2-6-1981

Biofeedback-enhanced vision training for strabismus

Marlene Inverso
Pacific University

Tricia Larsen
Pacific University

Biofeedback-enhanced vision training for strabismus

Abstract

It was the purpose of this study to explore the use of auditory biofeedback strabismus therapy prior to conventional visual therapy and to determine if a functional cure was possible with such a strabimnus therapy program. The results were that for five patients with a good prognosis for binocularity and regular attendance of training sessions, a functional cure was effected. For those patients with a poor prognosis for binocularity, the biofeedback portion of the therapy decreased the magnitude of the angle of deviation or taught ocular alignment, but did not appear to affect the sensory anomalies which prevented a functional cure. Those patients with anomalous angles, horror fusionis, deep amblyopia, deep eccentric fixation, and incomitancy had the same problems at both the beginning and the end of the study.

Degree Type

Thesis

Degree Name

Master of Science in Vision Science

Committee Chair

Harold M. Haynes

Subject Categories

Optometry

BIOFEEDBACK-ENHANCED VISION TRAINING FOR STRABISMUS

Marlene Inverso and Tricia Larsen

Thesis
In Partial Fulfillment of the Requirements for a Doctorate of Optometry

February 6, 1981

Pacific University College of Optometry

BIOFEEDBACK-ENHANCED VISION TRAINING FOR STRABISMUS

Marlene Inverso and Tricia Larsen

Thesis

In Partial Fulfillment of the Requirements for a Doctorate of Optometry

APPROVED BY

ADVISORS

Harold M. Haynes, O. D.

Donald Schuman, O. D.

Robert Yolton, O. D., PHD

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The authors would like to thank their three advisors for all their help and encouragement: Dr. Robert Yolton, Dr. Don Schuman, and Dr. Harold Haynes. They would also like to thank the Optometric Extension Program for their grant which provided money to develop the Hirons and Yolton auditory biofeedback equipment used in this study.

ABSTRACT

It was the purpose of this study to explore the use of auditory biofeedback strabismus therapy prior to conventional visual therapy and to determine if a functional cure was possible with such a strabismus therapy program. The results were that for five patients with a good prognosis for binocularity and regular attendance of training sessions, a functional cure was effected. For those patients with a poor prognosis for binocularity, the biofeedback portion of the therapy decreased the magnitude of the angle of deviation or taught ocular alignment, but did not appear to affect the sensory anomalies which prevented a functional cure. Those patients with anomalous angles, horror fusionis, deep amblyopia, deep eccentric fixation, and incomitancy had the same problems at both the beginning and the end of the study.

This study is a continuation of a research project on the role of auditory biofeedback strabismus therapy using the equipment developed by Hirons and Yolton.[1] The purpose of this phase of the project was to explore the use of auditory biofeedback visual therapy in a training program with auditory biofeedback used prior to conventional visual training for twelve strabismic patients in an institutional clinic setting. This clinical evaluation was designed as a series of case studies rather than a controlled clinical study so that information could be gathered about the use of auditory biofeedback to determine if a controlled clinical study would be of value.

Why use auditory biofeedback in visual training for strabismus? Flom indicates that auditory biofeedback "provides ... accurate error signals that can be promptly used to aim the eye...thus...auditory feedback [is] ...a means of accelerating the improvement of oculomotor performance which occurs gradually with some therapies."[2]

Does auditory biofeedback work? There has been some success using it to train fixation anomolies,[2] amblyopia,[3] nystagmus,[4] accommodation,[5,6] ocular pursuits,[7,8] and to decrease limitation of gaze.[9] Granger and Letourneau[7] reported that because auditory biofeedback indicates to the patient immediately when he has made a correct eye movement, the patient is able to repeat the correct behavior more frequently and thus shorten learning time. Letourneau and Ludlam[9] indicated that their patient was more motivated and less frustrated using auditory biofeedback to correct a limitation of gaze than she was using the traditional visual feedback training, and as a consequence, she made more progress using the auditory biofeedback.

Can auditory biofeedback teach eye alignment in strabismus? Cooper and Feldman[10] used an EOG set-up with transmitters to indicate with a tone that the patients' eyes were not aligned. The patients were instructed to move their eyes to shut off the tones and were able to do so even though they were exotropes. Palmer and Siegal used electromyographic feedback to partially reduce strabismic deviation and suggested that it may have a place in strabismus therapy.[11]

Hirons and Yolton[1] developed an auditory biofeedback system using trial frame mounted infrared sensors which caused a tone to sound if the patient's eyes were not aligned. In the first[1] and second[12] study using this equipment it was found that this technique could teach ocular alignment. The first study used auditory biofeedback as the sole strabismus therapy whereas the second study integrated biofeedback into a conventional strabismus therapy program. The authors of the second study suggested that the best use of biofeedback may be to teach motor alignment prior to traditional sensory visual training rather than integrate it with this training.[12]

It is therefore the purpose of this study to determine if auditory biofeedback, using the Hirons and Yolton equipment, may be judged helpful in strabismus therapy when it is used prior to conventional visual training. (Here conventional visual training is defined as the traditional optometric and orthoptic methods of developing monocular, biocular, and binocular visual skills in motilities, fixations, vergence and accommodative amplitude and facility, and stereoscopic functions.) It is also the purpose of this study to discuss whether a functional cure is possible using a combined program of auditory biofeedback and conventional strabismus training.

DESIGN OF THE STUDY

In this study, each patient underwent a visual exam, baseline measurements with the biofeedback equipment in place, biofeedback therapy to teach motor alignment of the eyes, and following this, conventional visual training to teach the visual skills necessary for adaptation and perceptual orientation to the new phoric eye posture. The biofeedback therapy was used until the patient demonstrated an orthotropic posture at all distances and was able to pass the biofeedback stress fields tests designed for this study. These tests were conducted with the biofeedback equipment in place to monitor ocular deviation and involved keeping an orthotropic posture for two minutes under the following conditions:

1. keeping letters clear at 16 inches and 14 feet while talking
2. looking at an empty field

3. looking at a vertical line field at both 16 inches and 14 feet
4. in the dark

Each subject who met the above criteria was then given traditional visual training for the development of satisfactory binocular motilities and clear, comfortable single binocular vision at all distances. This training involved the use of conventional visual training exercises for binocular dysfunction (see Figure 1) and was administered with two in-clinic sessions a week and daily home training of 30 minute sessions. The patients were considered "cured" if they met Flom's[12] and Ludlam's[14,15] criteria of a functional cure: the patient must have "clear, comfortable single binocular vision at all distances up to the near point of convergence which itself is normal, ...stereopsis and normal ranges of motor fusion."[13] The patient must also have good ocular motilites,[14,15] be phoric 99% of the time,[13] and may wear "corrective lenses and small amounts of prism (up to 5$^{\Delta}$)" to effect a phoric posture.[13]

THE EQUIPMENT

The auditory biofeedback equipment used was developed by Hirons and Yolton[1] and consisted of two pairs of infrared sensors mounted on the lower portion of trial frame eyewires. The sensors were positioned so that, when the trial frame was adjusted properly on the patient's face, the sensors pointed at the nasal and temporal limbi of each eye. The sensors were connected to a differential amplifier which emitted a tone when an eye deviated. The tone varied in pitch depending on how large the deviation was: a high pitch indicated a large deviation and a low pitch indicated a small deviation. Thus, the patients could "hear" their eye movements as they brought their eyes into an orthotropic posture.

SUBJECTS

Twelve strabismic patients participated in this study. They ranged in age from 7 to 45 years and included both esotropes and

exotropes. Eleven had been patients in an institutuinal clinic prior to their participation in the study and one was referred by a private practitioner. The patients' visual histories and characteristics are summarized in Figure 2 and a description of each follows:

Case 1

Case 1 was a ten year old female with comitant intermittent alternating divergence excess exotropia and hypertropia. This periodic exotrope entered the present study with an objective and a subjective angle of 22^{Δ} BI at 20 feet and 12^{Δ} BI at 16 inches, and 2^{Δ} right hypertropia as measured by the cover test and amblyoscope. (Since the subjective angle was the same as the objective angle when both were measured simultaneously, it appeared there was no angle of anomoly.) She was slightly hyperopic (SBVA*: OD +.50 and OS +.25) with an unaided Snellen visual acuity at 20 feet of OD 20/20 and OS $20/20^{-1}$ and a corrected (SBVA) Snellen visual acuity at 20 feet of OD 20/15, OS 20/20. She had normal fixation in each eye as observed with visuoscopy, and was able to demonstrate unification (3° fusion) in the amblyoscope and with Keystone card skills. Even though she suppressed the deviating eye when exotropic, she appeared to have normal monocular and binocular visual direction. She had had no previous surgery, training, or spectacles.

Case 2

Case 2 was a ten year old male with comitant intermittent alternating exotropia. He entered the present study with an objective and a subjective angle of 30^{Δ} BI at both 20 feet and 16 inches, as measured by the cover test and amblyoscope, but he was able to reduce this angle to zero momentarily for a near task demand, such as the stereopsis tests by Wirt (Randot.) However, he could not sustain this orthotropic posture for more than the fraction of a second that it took to make a response. (Since the subjective and objective angles were the same when both were measured simultaneously, it appeared that there was no angle of anomoly.) He was a low hyperopic astigmat (SBVA: OD +.50-.25x135; OS +.25-.25x90) with an unaided Snellen visual acuity at 20 feet of OD $20/20^{-3}$, OS $20/25^{-1}$ and a corrected Snellen visual acuity at 20 feet of OD 20/20, OS 20/20. He had normal

*Subjective refraction to best visual acuity

fixation in each eye as measured by visuoscopy and was able to demonstrate unification (3° fusion) with the amblyoscope and Randot (20" stereopsis) even though he suppressed when exotropic. It appeared, therefore, that he had normal monocular and binocular visual direction. He had had no previous surgery, training, or spectacles.

Case 3

Case 3 was a seven year old male with comitant intermittent alternating divergence excess exotropia. This periodic exotrope entered the present study with an objective and a subjective angle of 25 $^{\Delta}$ BI at 20 feet and 8 $^{\Delta}$ BI at 16 inches, as measured by the cover test and amblyoscope. (Since the subjective angle was the same as the objective angle when both were measured simultaneously, it appeared that there was no angle of anomoly.) He was a low myopic astigmat (SBVA: -.25-.25x90 OU) with an unaided Snellen visual acuity at 20 feet of OD $20/15^{-1}$, OS $20/20^{-1}$ and a corrected Snellen visual acuity at 20 feet of OD 20/15, OS 20/20. He had normal fixation in each eye as measured by visuoscopy, and was able to demonstrate unification (3° fusion) with the amblyoscope even though he suppressed when exotropic. It appeared, then, that he had a normal monocular and binocular visual direction. However, he had extremely poor monocular and binocular motility skills: pursuits, rotations, and saccades. He had had no previous surgery, training, or spectacles.

Case 4

Case 4 was a twenty-three year old female with comitant intermittent unilateral right exotropia. Her exotropia increased at times when she reported that she was going through physical or mental stress. She entered the present study with an objective and a subjective angle of 16 $^{\Delta}$ BI at both 20 feet and 16 inches, as measured by the cover test and amblyoscope. (Since the subjective angle was the same as the objective angle when both were measured simultaneously, it appeared that there was no angle of anomoly.) She was a low myopic astigmat (SBVA: OD -.50-.50x 30; OS -.25-.25x105) with an unaided Snellen visual acuity at 20 feet of OD $20/25^{-1}$, OS $20/15^{-3}$ and a corrected Snellen visual acuity at 20 feet of OD $20/20^{+1}$ and OS $20/15^{-1}$. She had normal fixation in each eye as observed with the visuoscope, and was able to demonstrate unification (3° fusion) with the amblyoscope even though she suppressed

when exotropic in the environment. It appeared, then, that she had normal monocular and binocular visual direction. She had had no previous surgery, training, or spectacles.

Case 5

Case 5 was a thirty-nine year old male with comitant intermittent alternating exotropia. He entered the present study with an objective and a subjective angle which varied between 26^{Δ} - 14^{Δ} BI at both 20 feet and 16 inches as measured by the cover test and amblyoscope. (Since the subjective angle was the same as the objective angle when both were measured simultaneously, it appeared that there was no angle of anomoly.) He was a myopic astigmat (SBVA: OD -.75-.50x115; OS -.50-.50x75) with an unaided Snellen visual acuity at 20 feet of OD 20/20, OS 20/20 and a corrected Snellen visual acuity at 20 feet of OD 20/20, OS 20/20. He was wearing spectacles with his SBVA correction at the time of the present study. He demonstrated normal fixation in each eye with the visuoscope and unification of 2° fusion with the amblyoscope. With red and green filters he was able to report luster for a very brief period but otherwise demonstrated suppression of the deviating eye or gave a split field response. He did respond to the Bielschowski After-Image test with an exact cross; thus it appeared that he could demonstrate normal correspondence. Although he had not had eye surgery, he had had eight weeks of auditory biofeedback training using Hirons and Yolton equipment two years prior to the present study.

Case 6

Case 6 was an eleven year old male with comitant unilateral left periodic exotropia and hypertropia. He entered the present study with an objective and subjective angle of 25^{Δ} BI at 20 feet and 20^{Δ} BI at 16 inches, as measured by the cover test and amblyoscope. These tests also showed a left hypertropia of 8^{Δ}. (Since the subjective angle was the same as the objective angle, it appeared that there was no angle of anomoly.) He was an anisometrope (SBVA: OD -.25-.25x90; OS +3.50-.25x90) with an unaided Snellen visual acuity at 20 feet of OD 20/20, OS 20/60 and a corrected Snellen visual acuity at 20 feet of OD $20/20^{+1}$, OS $20/60^{+2}$. He reported a difference in image size (aniseikonia) when uncorrected as well as when wearing a +3.50 Durasoft contact lens on the left eye. Although he did own this contact lens

for his left eye, he indicated that he wore it for a few weeks and then put it away.) The left eye demonstrated eccentric fixation with the visuoscope, was amblyopic, and did not appear to respond to lenses. Using a transferred after image and Haidinger brushes, it was determined that his correspondence was normal even though his fixation was eccentric. With red and green glasses he was able to get luster briefly, but mostly he got one color or the other. He was able to give 1° fusion responses in the amblyoscope, but could not achieve unification of 2° fusion because one eye appeared to suppress as soon as the images were brought close together. Therefore it appeared that although his monocular visual direction was not normal, his binocular visual direction was normal although poorly developed. He had had seven weeks of traditional strabismus visual training two years before the present study which appeared to effect no difference in his eye posture. He indictated that his motivation and attendance had been poor during this previous training and that he had rarely done his homework.

Case 7

Case 7 was a twenty-eight year old female with comitant intermittent unilateral left exotropia and hypertropia. This periodic exotrope entered the present study with an objective and a subjective angle of 55^{Δ} - 20^{Δ} BI at 20 feet and 45^{Δ} - 20^{Δ} BI at 16 inches, as measured with the cover test and amblyoscope. (Since the subjective and objective angles were the same, it appeared that there was no angle of anomoly.) She also had a variable right hypertropia of 10^{Δ} - 20^{Δ}. She was a high myope and anisometrope (SBVA: OD -7.75-.25x030; OS -18.00 sph) and was wearing the SBVA correction for the right eye but about -6.75 sph for the left eye when she entered the present study. Her unaided Snellen visual acuity at 20 feet was OD 10/200 and OS 3/200 and her Snellen visual acuity at 20 feet with the SBVA correction was OD $20/20^{-4}$ and OS 6/200. She had normal fixation in the right eye but no macular reflex, poor fixation, cover nystagmus, and high myopia with deep amblyopia in the left eye. She was able to demonstrate 1° fusion with the amblyoscope, but further unification was prevented because of suppression and amblyopia of the left eye. Red and green glasses showed a suppression response, although some luster

was attained briefly in the amblyoscope with red and green filters. It was difficult to obtain responses on the correspondence tests because of the poor responses of the left eye to Haidinger brushes but it appeared that normal correspondence was possible because of the brief luster responses. She had had no previous surgery or traditional visual training, but had had 14 weeks of auditory biofeedback training for exotropia using the Hirons and Yolton equipment six months prior to the present study. Prior to that training she had been a constant left exotrope of about 55$^{\Delta}$ BI. At the beginning of this study she could bring her eyes into cosmetic alignment for a few minutes but said her vision was very blurred with her eyes in this position. With her eyes in cosmetic alignment, her best subjective visual acuity was 20/40 with a -20.00 sphere in front of her right eye. (There was no difference in responses when lenses were placed before her left eye.)

Case 8

Case 8 was a nine year old non-comitant constant unilateral right exotrope with a V syndrome, hypertropia, and cyclotropia. The exotropia occurred subsequent to a traumatic eye injury which also left him with corneal scarring. He entered the present study with an objective and a subjective angle of 40$^{\Delta}$ - 30$^{\Delta}$ BI at 20 feet and at 16 inches as measured by the cover test and amblyoscope. The near exotropia was reduced if the measurement was taken in the inferior gaze. He had a variable left hypertropia of 2$^{\Delta}$ - 7$^{\Delta}$ and 24° of right excyclotropia. (Since the subjective angle was the same as the objective angle when both were measured simultaneously, it appeared there was no angle of anomoly.) He was slightly hyperopic (SBVA: OD +.50, OS +.25 spheres) and did use reading glasses (+.50 spheres) although he did not wear a correction otherwise. He had been fitted with a hard corneal contact lens in an attempt to mask the corneal scarring but it was uncomfortable and use was discontinued. Unaided the right eye was 20/50 but with the contact lens it was 20/30 at 20 feet; unaided and corrected the left eye was 20/15 at 20 feet. With visuoscopy, normal fixation was observed with the left eye and a searching eccentric fixation was observed with the right eye. He was able to demonstrate unification (3° fusion) with

the amblyoscope but had no measurable stereopsis in the environment. He intermittently suppressed his right eye, but on other occasions was aware of a "ghost image." Therefore, it appears that although the monocular visual direction is disturbed in the right eye, he can demonstrate normal binocular visual direction in the amblyoscope. He had had surgery following the eye injury in an attempt to repair the eye, but had not had any strabismic surgery. Previously he had had fifteen weeks of traditional visual training for strabismus which terminated three months before the present study began.

Case 9

Case 9 was a forty-five year old male with comitant alternating constant exotropia and hypertropia. He entered the present study with an objective angle of 55^{Δ} BI at both 20 feet and 16 inches as measured by the cover test and the amblyoscope. His subjective angle, as measured by the amblyoscope, was 39^{Δ} BI which gave him an angle of anomoly of 16^{Δ}. He had a variable left hypertropia of 1^{Δ} - 2^{Δ}. He was a hyperopic astigmatic presbyope (SBVA: +3.25-1.00x78 OD; +3.00-.25x90 OS with a +1.75 add) who was fully corrected at the time of the present study. His unaided Snellen visual acuity at 20 feet was OD 20/200 and OS 20/300 and his corrected (SBVA) Snellen visual acuity at 20 feet was OD 20/15 and OS 20/20. He had normal fixation in each eye as observed with visuoscopy, but could only achieve a unification of 1° fusion in the amblyoscope. A horror fusionis reaction occurred whenever 2° fusion was attempted (i.e. the tractor would move across to the other side of the garage but would never go in the garage.) He gave a Y response with the Brock string with 38^{Δ} - 39^{Δ} BI, but with 55^{Δ} BI he suppressed one of the strings. With red and green lenses he reported a split field and brief, fraction-of-a-second luster. Because his subjective angle was less than his objective angle, and because his objective angle was not equal to his angle of anomoly, it appeared that he had an unharmonious anomolous correspondence. The responses with the amblyoscope, Brock string, and red green lenses appear to support this conclusion. He had had two strabismic surgeries and vision training between the ages of six and eight years.

Case 10

Case 10 was a fifteen year old male with noncomitant alternating intermittent esotropia, double hypertropia, and cyclotropia. This periodic strabismic demonstrated an objective angle of 25^{Δ} - 18^{Δ} esotropia with 14^{Δ} left hypertropia and 10^{Δ} right hypertropia at 20 feet, and the same lateral prism at 16 inches with 20^{Δ} left hypertropia and 10^{Δ} right hypertropia. These objective angles were obtained with the cover test and the amblyoscope. The subjective angle was zero laterally and 2^{Δ} left hypertropia on both the cover test and the amblyoscope. (This gave him a lateral angle of anomoly equal to his objective angle.) The amblyoscope also revealed a 3° left cyclotropia. He was slightly hyperopic (SBVA: OD +.50 sphere; OS +.50-.75x20) and was uncorrected at the time of this study. His uncorrected Snellen visual acuity at 20 feet was OD 20/20, OS $20/25^{+4}$ and corrected with his SBVA: OD 20/15 and OS 20/20. He had a cover nystagmus in both eyes and an unsteady fixation in each eye as observed with the visuoscope. He demonstrated 2° fusion in the amblyoscope but could not appreciate unification of 3° fusion although he could appreciate some blue and yellow color mixture. (Red and green glasses testing could not be used because he was a Deuteranope.) Although there was unsteady fixation with the visuoscope, he was able to demonstrate a perfect cross on the Bielschowski After Image test. Normal correspondense was also demonstrated with the transferred after image and Haidinger brushes. Although his angle of anomoly was equal to his objective angle, which might have indicated a harmonious anomolous correspondence, he was able to demonstrate normal correspondence on these two tests. He had had strabismus surgery as an infant and twenty-two weeks of traditional visual training for strabismus which had terminated five months prior to the present study.

Case 11

Case 11 was a forty-two year old male with noncomitant, constant unilateral right esotropia, hypertropia, and cyclotropia. He had an objective angle of 14^{Δ} BO at both 20 feet and 16 inches, as measured by the cover test and amblyoscope. His subjective angle was 45^{Δ} BO at both distances, also as measured by the cover test and amblyoscope, which gave him an angle of anomoly of 31^{Δ} (paradoxical.) The amblyoscope

revealed a 1^{Δ} - 7^{Δ} left hypertropia and 6° right cyclotropia. He was a myopic astigmat (SBVA: OD -.75-1.25x90; OS -1.75-.50x80) who was fully corrected at the time of the present study. His unaided Snellen visual acuity at 20 feet was OD 20/200 and OS $20/100^{+1}$ and corrected (SBVA) at 20 feet was OD 20/200 and OS $20/20^{-5}$. He had normal fixation in the left eye and eccentric fixation in the right eye, as observed with Haidinger brush placement in relation to letters. He demonstrated slight unification (1° fusion) and horror fusionis with the amblyoscope and could not appreciate luster with red and green glasses. Neither could he transfer an after-image so it was difficult to determine his correspondence except to note that he gave a split field response with the red and green glasses and he constantly saw double subsequent to his last surgery. He had had no previous visual training but had undergone strabismic surgery as a child and again at the age of forty-one.

Case 12

Case 12 was an eleven year old male with comitant, constant unilateral right esotropia. He entered the present study with an objective angle of 80^{Δ} BO at both 20 feet and 16 inches, as measured by the cover test amblyoscope. His subjective angle was difficult to measure because of his poor responses, so at this point it cannot be said whether or not he has an angle of anomoly. He was a corrected hyperope (SBVA: OD +2.50 sphere and OS +1.00) with an uncorrected VA on the Snellen chart at 20 feet of OD 20/200 and OS 20/20 and corrected at 20 feet OD 20/200 and OS 20/20. He indicated that he only wore his glasses in school and that he left them there. He had normal fixation in the left eye but eccentric fixation in the right eye as measured by visuoscopy and Haidinger brushes. He had only slight unification (1° fusion) in the amblyoscope : deep suppression and amblyopia appeared to prevent further unification responses. He does not appear to be able to respond to the transferred after image tests or to the Brock string so it was not possible to ascertain his retinal correspondence with certainty. He had had no previous surgery but had had twenty weeks of traditional visual training for his amblyopia which terminated four months prior to the present study.

TRAINING REGIMEN

Prior to the biofeedback program a visual examination was given and each patient had two daily baseline measurements of ocular deviation take with the infrared sensor trial frame in place. Immediately before and after the daily biofeedback sessions, each patient had ocular deviations measured with the biofeedback equipment in place. These measurements were made using a cover test and a prism bar or loose prisms. In some cases, the Hirshberg test was used to confirm a measurement.

The study was designed so that each patient would attend five consecutive daily sessions a week with each session involving twenty minutes of biofeedback training, divided into two-minute periods with a thirty-second break between each period. Four two-minute periods were given with a target at 16 inches and four with a target at 14 feet. The targets consisted of 20/20 letters calculated for 16 inches and 14 feet so that accommodation could be controlled.

At the beginning of each biofeedback training session the strabismic patients had the trial frame placed securely before their eyes and fastened around their heads with an athletic band to prevent slippage and assure consistent positioning of the infrared sensors. (A chin rest was used to keep the head steady but it was found that a bite bar was not necessary.)

Each eye was alternately covered while the other was looking at a target so that the sensors could be pointed at the limbi of each eye while the eye was in an ortho position. Then the subjects were instructed to look at the target with both eyes and to move their eyes to lower the pitch of the sensor tone or to turn the sound off, if they could, while keeping the target clear. Prisms and lenses were used to aid the patient in making small ocular motor movements at a time. For example, if the ocular deviation was 55^{Δ} BI, 45^{Δ} BI was placed in the trial frame (using Fresnel prisms with these large deviations) and the sensors were aligned with the eye in this position monocularly; then both eyes were allowed to look at the target and the equipment was turned on. The tone sounded when the patient took up his usual 55^{Δ} BI position, but as soon as he moved his eye to the position of lesser

deviation (45$^{\Delta}$ BI) the tone turned off. The amount of prism was then slowly decreased until no prism was necessary and the patient could make a motor movement from the deviating to the ortho position.

RESULTS

The results of the twelve cases receiving both biofeedback training and conventional training are summarized as individual case studies following this brief overview:

The population trained consisted of eight comitant exotropes, one noncomitant exotrope, and three comitant esotropes. Hypertropia was associated with five exotropes and two esotropes. Cyclotropia was associated with one exotrope and two esotropes.

Five of the cases were determined to be functionally cured by Flom's criteria. Of the remaining seven cases, three passed some of the biofeedback stress fields tests but none developed adequate levels of binocular motor skills (convergence, divergence, or vertical vergence skills) or advanced unification responses (stereoacuity better than 70" or other stereoscopic functions.)

An angle of anomly was measured in three cases and horror fusionis in two cases at both the beginning and end of training. Of the three cases with eccentric fixation, two showed eccentric fixation at the conclusion of the study but all three amblyopes who received amblyopia training showed a decrease in their amblyopia at the end of the study. Case 10 had to terminate therapy before the end of the study due to a auto accident which resulted in broken limbs.

A description of each subject's training and resultant visual changes is given below and summarized in Figure 4:

Case 1 (Comitant intermittent alternating divergence excess exotropia and hypertropia)

This female, age 10, attended five biofeedback sessions a week and at the beginning of the fifth week (21 sessions) she was orthotropic at all distances and was able to pass the stress fields tests. Her posture, as measured by a cover test with and without the biofeedback apparatus in place, had changed from 22$^{\Delta}$ BI at 20 feet and 12$^{\Delta}$ BI at 16 inches to Ø at these distances. There was no vertical tropia. At this point in her visual therapy she could appreciate 30" of stereopsis on the Randot. Conventional visual training was begun at this point which stressed accommodative and convergence amplitude and facility training, eye-hand coordination training, monocular, biocular and binocular motility training, and training for a group of stereoscopic skills. After two weeks (six office hours and ten half-hour home training sessions) of conventional training she achieved 20" appreciation of stereopsis on the Randot and a complete visual examination revealed that she had met Flom's criteria of a functional cure. Although the change in her refractive error (SBVA) was within measurement error (-.25 sphere OD and -.25x20 OS), Case 1 showed a need for plus in her near retinoscopy and near cross cylinder responses (+1.25 to +1.50) and so reading glasses were recommended. However, Case 1's parents decided against glasses for their daughter. Four months after she met Flom's criteria, Case 1 was retested and although ortho on the cover test at all distances, there was an intermittent suppression on the AO vectographic chart at 20 feet and some instability of the letters on the AO near vectographic chart. The instability was reduced with +1.00 to +1.50 at near, but reading glasses were again rejected by her parents. The patient indicated that she periodically skipped lines when reading but otherwise did not have any visual complaints. The mother indicated that she had not noticed her daughter's eyes deviating since the visual training program had terminated.

Case 2 (Comitant intermittent alternating exotropia)

This male, age 10, attended five biofeedback sessions a week for five weeks and at the beginning of the sixth week (27 sessions) he was orthotropic at all distances and was able to pass the stress fields tests. His posture, as measured by a cover test with and without the biofeedback apparatus in place, had changed from 30^{Δ} BI at both 20 feet and 16 inches to Ø at all distances. Conventional visual training was begun at this point which stressed anti-suppression training, accommodative and convergence amplitude and facility training, eye-hand coordination training, monocular, biocular, and binocular motility training, and training for a group of stereoscopic skills. After five weeks (nine office hours and twenty-five half-hour home sessions) of conventional training he had met all of Flom's criteria for a functional cure and had achieved 20" appreciation of stereopsis on the Randot which he could maintain for an indefinite period. (This was in contrast to his pre-training program performance where he could appreciate the stereopsis for only a brief fraction of a second.) His post-training refractive error (SBVA) increased in plus by .75 sphere with a small cylinder change and so a prescription of +.75 spheres OU was dispensed for full-time wear. Three months after he had met Flom's criteria, Case 2 was retested and a case history was taken. The family reported that the boy's eyes would deviate if he was daydreaming but that he could immediately bring them back into alignment when he was reminded. The testing revealed an exophoria of 3^{Δ} BI at distance and 9^{Δ} BI at near and clear, comfortable, single binocular vision at all distances. Case 2 was using his glasses for all day wear and did not have any visual complaints.

Case 3 (Comitant intermittent alternating divergence excess exotropia)

This male, age 7, attended five biofeedback sessions a week for two weeks and at the end of two weeks (9 sessions) he was orthotropic at all distances and was able to pass the stress fields tests. His posture, as measured by a cover test with and without the biofeedback apparatus in place, had changed for 25^{Δ} BI at 20 feet and 8^{Δ} BI at 16 inches to Ø at all distances. Immediately following biofeedback

training he could appreciate 100" stereopsis on the Randot. Conventional training was begun at this point which stressed accommodative and convergence amplitude and facility training, eye-hand coordination training, anti-suppression training, monocular, biocular, and binocular motility training, directionality training, and training for a group of stereoscopic skills. Home training was assigned but rarely completed due to poor motivation on Case 3's part. Three office training sessions were missed due to the fact that Case 3 was hospitalized for a foot infection and two other training sessions were missed due to illness. Seven weeks after conventional training was begun (fourteen office hours), he achieved 20" appreciation of stereopsis on the Randot and a complete visual examination revealed that he had met Flom's criteria of a functional cure. However, although he had clear, comfortable, single binocular vision at all distances, his ocular motilities were poor (irregular pursuit and tracking with an inability to sustain fixation or make efficient saccades). His reversal and laterality problems had not improved significantly since pre-training measurements, although he did improve in his directionality. Therefore, although he had met Flom's criteria of a functional cure, he had not met Ludlam's criteria.[14,15] It was recommended that he continue with comventional training; however, because his eyes were straight, motivation was poor and training was temporarily terminated. His post-training refractive error (SBVA) increased in plus by .50 sphere and by .25x90 cylinder OU. Near retinoscopy and cross cylinder testing revealed that a +1.00 at near provided stable and comfortable binocularity and so bifocals were prescribed with +.25 spheres at distance and +1.00 spheres at near. Four months after he had met Flom's criteria, Case 3 was retested and a case history taken. The mother reported that his eyes deviated when he looked at distant objects about 10% of the time and that he was not complying with wearing his glasses. His complaint was that his spelling and handwriting continued to be poor and it was noted that his spelling errors continued to reveal reversal problems and poor visual memory. It appeared that these visual problems were directly related to his poor ocular motilities and it was recommended that he begin visual

training again as well as use his glasses for full-time wear. Due to a change in attitude of Case 3 and his family and an increased awareness on their part of his visual needs, Case 3 began conventional visual training again for his remaining areas of visual skill deficiencies.

Case 4 (Comitant intermittent unilateral right exotropia)

This female, age 24, sporadically attended two biofeedback sessions a week for four months. After fifteen biofeedback sessions she passed the first three stress fields tests but could not maintain an ortho posture in the dark. She could attain an orthotropic posture, as measured by a cover test with and without the biofeedback apparatus in place, at all distances on days in which she reported that physical or mental stress factors were minimal. (Physical stress factors included orthodontial work and dysmenorrhea; mental stress factors included responsibility for the care of two invalid relatives.) Because she has not yet passed all the stress field tests, she is continuing biofeedback sessions and has not yet begun conventional visual training. It is felt that if she could have attended biofeedback sessions for five days a week instead of two, and if she could have maintained regular attendance, her progress might have been faster despite the complicating stress factors which she reported.

Case 5 (Comitant intermittent alternating exotropia)

This male, age 39, attended five biofeedback sessions a week for two weeks and at the end of the two weeks (nine sessions) he was orthotropic at all distance and was able to pass the stress fields tests. His posture, as measured by cover test with and without the biofeedback apparatus in place, had changed from 26^{Δ} - 14^{Δ} BI at both 20 feet and 16 inches to Ø at all distances. At this time he could appreciate 20" stereopsis on the Randot but he could not maintain this stereopsis for more than a fraction of a second. Conventional visual training was begun after biofeedback therapy was concluded. The conventional training stressed anti-suppression training and included accommodative and convergence amplitude and facility training, eye-hand coordination training, monocular, biocular, and binocular motility training, and training in unification including various types of stereotraining. After thirteen weeks

(thirteen office hours and thirty half-hour home sessions) of conventional visual training he achieved 20" appreciation of stereopsis on the Randot which he could maintain for an indefinite period. He had clear, single, comfortable binocular vision 99% of the time and therefore met Flom's criteria of a functional cure. Although there was no change in refractive error after his visual therapy program, his near retinoscopy and cross cylinder test responses indicated that he had a need for +.50 to +1.00 over his SBVA when doing near work. It was therefore recommended that he take his glasses off for reading or use bifocals for reading. He decided to take the former option. Two months after he met Flom's criteria, Case 5 was retested and a case history taken. He noted that his eyes deviated if he was daydreaming and that they would also deviate towards the end of a stressful day. He could immediately bring his eyes into alignment if an eye deviated but the fact that his eyes deviated 5% rather than 1% of the time put him into Flom's "almost cured" category. It was recommended that he continue with anti-suppression home training so that diplopia would continue to remind him of any deviation.

Case 6 (Comitant unilateral left periodic exotropia and hypertropia)

This male, age 11, was given home fixation training for left eye eccentric fixation and amblyopia four weeks prior to his biofeedback therapy for strabismus. Although this study intended to use biofeedback therapy prior to conventional training, it was decided to give Case 6 the conventional fixation training first because he wanted to get started with therapy immediately even though he was going on vacation. The home therapy was given so that he could begin his training while on vacation. As a result of this fixation training for his left eye (which included monocular eye-hand coordination and accommodative amplitude and facility training), Case 6's posture changed from 25^{Δ} BI at 20 feet and 20^{Δ} BI at 16 inches to 14^{Δ} BI at 20 feet and Ø at 16 inches. His left eye acuity at distance improved from 20/60 to 20/40 and near acuity from 20/60 to 20/30. He attended five biofeedback sessions for one week and at the end of that week he was orthotropic at all distances and was able to pass the stress field tests. After

five bioffedback sessions his posture, as measured by cover test with and without the biofeedback apparatus in place, changed from 14^{Δ} BI at 20 feet and Ø at 16 inches to Ø at all distances. There was no vertical tropia remaining but there was a 1^{Δ} right hyperphoria. Conventional biocular and binocular training was begun at this point which stressed anti-suppression training, accommodative and convergence amplitude and facility training, eye-hand coordination training, motility training, and training in stereoscopic skills. This conventional training also included continued monocular training for left eye fixation and amblyopia. After 19 weeks of conventional training (46 office hours and approximately 30 half-hour home training sessions), Case 6's visual acuity in the left eye (SBVA) was 20/20 at 16 inches and $20/25^{+3}$ (single letter) at 20 feet. At that time he had met Flom's criteria for a functional cure and stereopsis was 30" on the Randot. Although his refraction (SBVA) did not change in his right eye, his left eye accepted the objective refraction (+3.50) which it previously had not responded to. Because spectacles which corrected his refractive error and aniseikonia were not cosmetically acceptable to him, he was subsequently dispensed a hydrogel contact lens for his left eye which gave him poorer acuity in the left eye ($20/30^{+3}$) than did the spectacles and which left a residual aniseikonia. After wearing this lens for a month, Case 6 reported that his left eye was deviating 5% of the time instead of 1%, and thus his cure then fell into the "almost cured" Flom criteria. The contact lens was changed form a spin cast to a lathe cut lens and it was found that the visual acuity improved to $20/20^{-4}$ and the aniseikonia was again corrected. He was asked to return in a month for further evaluation.

Case 7 (Comitant intermittent unilateral left exotropia and hypertropia)

As a result of previous biofeedback training using the Hirons and Yolton equipment, this female, age 28, was able to make a motor movement to align her eyes within 20^{Δ} BI of ortho. But with this nearly cosmetic alignment her vision was blurred because she used accommodative convergence to align her eyes. Although she could use her cosmetically acceptable eye posture when her picture was being taken, it was not usable in any

other respect because she could not see clearly unless she wore a -20.00 sphere for the right eye. (With a -20.00 sphere OD she could barely read the 20/40 line.) Since her refractive error in the right eye was -7.75-.25x30 ($20/40^{-4}$ SBVA), it appeared that about 12 diopters of accommodation (OD) was simultaneously activated with alignment of binocular fixation. (The left eye was amblyopic: -18.00 sphere objective refraction with a 6/200 visual acuity. The OU visual acuity was the same whether or not this eye was corrected and near and far AO vectographic testing indicated that the visual input from the left eye was suppressed when both eyes were looking at the target.)

Biofeedback in the present study for Case 7 involved reducing the minus sphere needed to keep the target (20/40) clear at 20 feet and 16 inches while she aligned her eyes (i.e. turned the biofeedback tone off.) During all the sessions -18.00 sphere (or -15.00 contact lens) was used for the left eye, but the right eye was given -20.00 sphere and then this minus was slowly reduced. After three and a half months of this biofeedback training she was able to clear a 20/40 target at 20 feet with -7.00 OD and a 20/20 target at 16 inches with -6.00 OD.

Simultaneously with biofeedback training, a home training program for amblyopia was instituted for Case 7's left eye. This training included monocular fixation exercises, accommodation facility and amplitude exercises, and eye-hand coordination exercises. Stripe therapy was also used for six weeks. (All amblyopia training was done with the right eye covered and the left eye wearing a -15.00 contact lens.) After three months of this home training her corrected acuity improved form 6/200 to $10/60^{-3}$ with the -15.00 contact lens. At this point, she could respond subjectively to lenses and an over-refraction revealed that a +1.00 in the spectacle plane provided the best subjective SBVA ($20/200^{+}$) for the left eye. Another lens was ordered for the left eye and amblyopia training was continued.

At this point in the training program Case 7 was given anti-suppression training to add to her home training program. After a month of using mirror superimposition, pola mirror techniques, and exercises with red and green glasses, Case 7 reported that she could bring her eyes into near alignment, see double, and then fine tune the alignment

by sliding one image over the other. Suppression still existed when her left eye was deviated 55^{Δ} - 40^{Δ}, but when she brought it into 20^{Δ} she could see double and fine tune the alignment.

For the first three and a half months of training, biofeedback therapy was given three days a week. But after Case 7 learned to fine tune her alignment, biofeedback therapy was given one day a week. The therapy consisted of holding her eyes in alignment while clearing a 20/20 target at both 20 feet and 16 inches. No lenses above the SBVA were used. This approach was used to reduce the remaining accommodation which Case 7 was using to converge her eyes. While listening for the tone, she also used visual feedback by trying to slip one image over the other. It is expected that she will pass the biofeedback stress fields tests in the near future. At that point, conventional binocular training will be instituted for accommodation and convergence facility and amplitude, eye-hand coordination training, binocular and biocular motility training, and training in appreciation of stereopsis. She continues to work on her home amblyopia and anti-suppression training.

Because of the nature of Case 7's visual problems, it was decided to depart from the original intention of this study: the provision of biofeedback before any conventional visual training. She had actually had biofeedback as the sole therapy mode for 4 weeks in a previous study. In the present study it was the intention to determine if biofeedback could continue to play a role in her total visual program.

Case 8 (Non-comitant constant unilateral right exotropia with a V syndrome, hypertropia, and cyclotropia)

This male, age 9, attended three biofeedback sessions a week for two months. Since he had a learning disability in addition to his exotropia, and since his parents wanted him to have visual training to improve his deficient visual skills which directly related to his learning problems, conventional visual training was instituted simultaneously with biofeedback. This conventional training program involved fixation, motility, and accommodation exercises which were completed at home.

Biofeedback was begun using near targets only to try to take advantage of the accommodative convergence. Prism was used at first to help him gain success with biofeedback: 20^{Δ} was placed in the trail frame

bank and he moved his eye until he got the machine quiet with this deviation. Then the prism was slowly reduced until it was not necessary. At that point, he became able to do pencil push-ups and near-far jumps and so these exercises were given to him as a part of his home training program. Biofeedback was continued simultaneously with these exercises. Because of transportation problems, he was only able to attend three biofeedback sessions a week for about six weeks and now he is only coming in for one biofeedback session a week. Since he began biofeedback and began to be successful in making motor movements, he took a new interest in his home training progran and has faithfully completed his exercises thirty minutes a day for at least five days a week. At present, his distance deviation remains at 35^{Δ} of exotropia with 5^{Δ} right hypertropia; however, at 20 inches his deviation is about 25^{Δ} with 5^{Δ} right hypertropia, at ten inches it is 14^{Δ}, and at five inches he is orthotropic. At 14 inches and his orthotropic distance the vertical tropia was reduced to zero. The cyclotropia was 24° when his deviation was 35^{Δ}, but the subject reported that the tilt straightened out as he slid one image over the other at 5". He continues to intermittently suppress to avoid diplopia, but his mother has noticed a cosmetic improvement when he looks at her at the table or during homework.

The biofeedback appeared to give Case 8 the confidence he needed to work on his eye problem. Prior to biofeedback training, he said that there was no way that he could bring his right eye into alignment when both eyes were open. But now, after twelve weeks of biofeedback and conventional visual therapy (27 sessions), he has a more optomistic outlook. He continues to work on accommodation training and motilities training at home and his work is monitored at the clinic during his weekly visits.

Case 9 (Comitant alternating constant exotropia and hypertropia)

Case 9 attended five biofeedback sessions a week for four weeks and as a result of this training, his objective angle had decreased from 55^{Δ} BI to 35^{Δ} BI. His subjective feeling was that now he was going around with his eyes crossed and this was giving him headaches. Although he could look in the mirror and see that his eyes were not crossed, he was uncomfortable with the feeling that they were crossed.

Biofeedback was discontinued and he was told to come back in three weeks. At the end of the three weeks his angle had returned to 55$^{\Delta}$ BI and he no longer had subjective complaints. It appeared that the large objective angle and unharmonious angle of anomoly of such long standing, as well as his horror fusionis response, contributed to his subjective discomfort when his objective angle was reduced and his angle of anomoly was changed from unharmonious to paradoxical. In view of the poor unification responses and subjective discomfort with visual therapy, it was decided to terminate visual therapy for Case 9.

Case 10 (Non-comitant alternating intermittent exotropia, double hypertropia, and cyclotropia.)

Case 10 attended four biofeedback sessions in one week before discontinuing therapy due to an accident which resulted in a broken ankle and leg. After four biofeedback sessions his lateral deviation was reduced from 18$^{\Delta}$ BO to zero and his vertical deviation was reduced from 10$^{\Delta}$ to 4$^{\Delta}$ in the right eye and from 20$^{\Delta}$ to 6$^{\Delta}$ in the left eye, @16". (The cyclotropia was not measured before he left the study since his termination of therapy was unplanned.) Although he has not been seen since his accident, it is not expected that his gains from biofeedback would hold since no sensory unification exercises were given and he did have an angle of anomoly as well as some remaining hypertropia.

Case 11 (Incomitant, constant unilateral right esotropia, hypertropia, and cyclotropia.)

Because Case 11 lived about 90 miles from the institutional clinic where the visual training was performed, he came two days a week and had two biofeedback sessions a day, one in the morning and one in the afternoon. He attended four biofeedback sessions a week for four weeks and at the end of the fifth week his lateral deviation was reduced from 14$^{\Delta}$ BO at both 20 feet and 16 inches to Ø at both distances. However, his subjective angle varied from 45$^{\Delta}$ - 35$^{\Delta}$ BO and he continued to report constant diplopia and to have a horror fusionis response in the amblyoscope. His vertical angle varied from 1/2$^{\Delta}$ to 3$^{\Delta}$ left hyper and his cyclotropia varied from 0° to 6°. Although he had only passed the 1st. biofeedback stress test at this time, it was decided to discontinue biofeedback therapy since the

objective angle reduction did not seem to have much effect on the subjective angle. He went on a vacation for a few months and when he returned, traditional visual therapy was begun to attempt to aid him in unification responses and reduction of his subjective angle. He attends these traditional visual therapy sessions once a week and completes thirty minutes a day of home visual training.

Case 12 (Comitant, constant unilateral right exotropia)

Case 12 attended twenty biofeedback sessions sporadically (sometimes three time a week, sometimes one time a week, and often a few weeks would pass between attendance.) Because Case 12 had an eccentric fixation and amblyopia (SBVA 20/200) in the right eye, a home training program for amblyopia was instituted simultaneously with biofeedback training. After five months of sporadic biofeedback and amblyopia training, his objective angle was reduced from 80$^{\Delta}$ BO to 65$^{\Delta}$ BO at all distances and his amblyopia reduced from SBVA 20/200 to 20/100 single letter.

Case 12 is one child of seven in a family which often lives with other relatives and changes residence every few months. He receives little support at home to complete his amblyopia exercises and is brought to the training sessions by different relatives each time. When he began biofeedback training he was enthusiastic because of the science-fiction nature of the equipment (i.e. it appeared to him this way,) and his enthusiasm increased as he learned to turn the tone off. With biofeedback sessions attended more regularly, it is possible that Case 12 would have made more progress. For as Flom[2] indicates, several short sessions close together in a week tend to facilitate learning when auditory biofeedback is used for visual problems.

DISCUSSION

The results indicate that for five strabismic patients who had a good prognosis for a functional cure,[13] a strabismus therapy program with auditory biofeedback used prior to conventional visual training was successful. Five of the seven patients who did not attain functional cures had a poor prognosis[13] for achieving binocular performance because of the presence of two or more visual anomolies: eccentric fixation, deep amblyopia, an angle of anomoly, horror fusionis, incomitancy, or cyclotropia. Of the remaining two patients who did not achieve functional cures, one (Case 10) had an accident at home and had to drop out of the study before his therapy was completed and the other (Case 4) had sporadic attendance. (In a time span of four months, she attended fifteen biofeedback sessions out of a scheduled thirty-two.)

Prognosis and regular attendance appeared to be factors in the length of time required to achieve the five functional cures. Other factors were the size of the angle, degree of fusion and unification present at the beginning of the study, and the motivation of the patient. When prognosis, angle, degree of fusion and unification are held constant, motivation appears to be an important factor. For example, the two fastest cures, Case 1 and Case 3, took six weeks and nine weeks respectively. They were both comitant divergence excess type intermittent exotropes with angles of 25$^{\Delta}$BI or smaller, no angle of anomoly, normal fixation and acuity in each eye, and an ability to respond to stereoscopic targets in the amblyoscope at the objective angle of strabismus. However, Case 1 needed only two weeks of conventional visual training whereas Case 3 needed seven weeks to obtain clear, single, comfortable binocular vision. The observable difference was the motivation of the patient to do home training and to attend office visual training sessions regularly. Case 1 was highly motivated to succeed, always made sure she had enough rest the night before a visual training office visit, and never missed a scheduled training session. In contrast, Case 3 was not motivated to do the home training, would stay up until 2:00 a.m. watching TV the night before a training session, and was unable to attend at least five scheduled training sessions. The difference

in motivation was in part due to a difference in age between these two cases: Case 1 was a mature ten year old who had already taken responsibility for herself and her actions in many respects at home and at school whereas Case 3 was an immature, hyperactive seven year old who rarely complied with social responsibilities at home or at school. He refused to observe bedtimes or other rules set by his mother and in general his mother gave in to him rather than fight. Consequently little home training was completed in the seven weeks of conventional therapy. In addition, during this time period he accidently stabbed his foot and was hospitalized for a few days.

Of the other three functional cures (Cases 2,5, and 6) Case 2 had the best prognosis and the fastest cure (ten weeks) compared to the fifteen and twenty weeks respectively needed for Cases 5 and 6. All three were highly motivated and mature but although Case 2 had a large angle (30 Δ BI at all distances), he had 3° fusion and was free of sensory anomolies except for suppression. His suppression was deeper than that of the two divergence excess exotropes (Cases 1 and 3) but not as deep as that of Cases 5 and 6, who could only achieve 2° fusion and 1° fusion respectively prior to the training program. In both Cases 5 and 6 the biofeedback training was relatively short (nine and five sessions respectively), but the conventional training portion of the therapy program was very long (thirteen office hours and forty-six office hours respectively) because of the patients' needs to overcome sensory anomolies such as deep suppression (Cases 5 and 6) and eccentric fixation with amblyopia and aniseikonia (Case 6). Thus, it appears that when motivation is proportionately equal, the degree of fusion and unification present prior to therapy is a factor in the amount of time needed to effect binocularity. If 3° fusion is present and there are no other sensory anomolies, the cure appears to be faster than if only first or second degree fusion are present prior to therapy.

A deep eccentric fixation and amblyopia is usually regarded as having a poorer prognosis than a shallow eccentric fixation and amblyopia. This appeared true for the present study. For example, Case 6 had a shallow eccentric fixation and amblyopia (SBVA of 20/60) initially whereas Case 7's unsteady fixation and amblyopia were deeper (SBVA of 6/200) and complicated by high myopia (-18.00 sphere objective refraction) before therapy. Case 6

attained a functional cure and 20/20 SBVA OU in twenty weeks whereas Case 7 was in the program for twenty-four weeks without a functional cure. She had improved her SBVA to 20/200+ and her fusion from 2° to 3°, but although she was able to fuse images, she still suppressed her left eye when it deviated. Other factors which also may have contributed to the length of time needed for a functional cure were that Case 7 had an angle twice as large as that of Case 6 (55^{Δ} BI vs. 25^{Δ}) prior to the therapy program and she had had her deviation for a longer period than had Case 6 (28 years vs. 10 years).

Case 12 had a poor prognosis in that he had a deep eccentric fixation and amblyopia (OD SBVA 20/200) as well as a very large objective angle (80^{Δ} BO) present since birth. His objective angle was reduced about 15^{Δ} in twenty biofeedback hours but his attendance was very irregular and sporadic covering a period of five months. No one in his family consistently monitored his home fixation and amblyopia training and so not as much work was completed at home as was assigned. Although his angle was large and his amblyopia deep, it was expected that should he have had consistent help with home training and regular attendence of biofeedback sessions, he would have been able to make more progress in five months.

Case 8's prognosis was complicated by incomitancy, organic amblyopia, hypertropia, and cyclotropia as well as a fairly large angle of deviation (40^{Δ} BI OD). That he was able to get third degree fusion in the amblyoscope was a factor in his favor. However, his motivation to do visual training was poor prior to the biofeedback because he felt that nothing could be done to straighten his eyes. He participated in the study only because he was interested in the science of the biofeedback. Once in biofeedback and able to experience the decrease in tone due to ocular position changes, he changed his mind and asked for exercises he could do at home to augment his therapy. Thus, the success with the biofeedback actually stimulated him to take an interest in the conventional visual training exercises which he had previously been exposed to but which he had dismissed as not being of much value to him.

Although objective angles were decreased for Cases 9 and 11, biofeedback did not have any effect on their angles of anomoly or horror fusionis..

Neither of these patients could attain 2° or 3° fusion either before or after the therapy program. In cases such as these, it may be more beneficial to begin visual therapy with work on the subjective angle, unification, and anomolous correspondence. Provision of an objective orthotropic angle without work on unification for Case 9 may have precipitated intractable diplopia had the therapy been continued. Case 11 already had intractable diplopia as a result of surgery which reduced his objective angle but which was not preceded or followed by training for unification.

For all cases, conventional visual training appeared to be necessary to effect a functional cure. This was due to the fact that unification (third degree fusion and stereoscopic skills) appeared to be the reinforcement for straight eyes: therefore, unless the patient could sustain unification there was not much reinforcement to hold his eyes in alignment even though biofeedback had taught him the motor movement to do so. Without unification, the ability to bring the eyes into alignment became an action the patient could perform but did not become a part of his normal ocular positioning. It appears, then, that only when sensory anomolies are eliminated (and therefore the roadblocks to unification are removed) will neuromuscular changes in ocular positioning take the place of old neuromuscular habits.*

But what mechanism is in operation during biofeedback which allows the patient to learn ocular alignment when unification is not present? According to Skavenski and Steinman[16] human eyes do have "extra retinal positional control" and therefore they can hold a fixation when there is no visual stimulation to do so. They attribute this positional control to both inflow and outflow information, although they do not know the mechanisms. Stretch receptors do exist in human extra ocular muscles but it has not been proven that they have a proprioceptive function which could account for the inflow information. Yet Skavenski[17] indicated that there was such a "felt position" which could be used to adjust the eye and to perceive if the eye was moving.

Skavenski[17] cited Helmholtz' work as proof of a neural outflow mechanism: the memory of the innervation pattern that provided motor movement to

* Harold M. Haynes, personal communication and Opt. 551, Optometry V notes. Pacific University College of Optometry, Spring 1980.

position the eye. He said that if humans did not have this outflow mechanism, they would not perceive the target as displaced when their eyes were restrained during an attempted ocular motor movement and they would not perceive the target as moving when their eyes were passively moved and the target held stationary. In other words, the neural outflow to the muscle must play a part in these perceptions. It may be this extra retinal positional control which the auditory biofeedback therapies[1-9,11,12] tap, even though the mechanism is not yet known and even though Monahan questions its existence[18] and suggests that the extraocular muscles have a movement sense but not a positional one.

Another mechanism may be in operation during biofeedback which allows the patient to learn ocular alignment: an increase in duction ranges. In conventional strabismus therapy a significant part of the training must involve an increase in forced prism vergence ranges so that the patient can call on vergence skills to align his eyes. In this study, duction ranges were not trained before biofeedback began, yet there appeared to be wide ranges immediately following the biofeedback portion of the study. Although duction ranges were not a part of the post-biofeedback testing, their increase was apparent not only by the fact that the patient could use vergence to align his eyes and hold that alignment, but also by the observation that the patient could perform with wide ranges on vectographs and stereoscopic tromboning when given these exercises for the first time following biofeedback. Why would duction ranges be quite large following biofeedback if they are not specifically taught? One reason may be that they were there all along but not observed with prebiofeedback testing because the patient could not respond to phoropter or loose prism duction tests. (A suggested protocol would be to take ductions in the amblyoscope at the angle of strabismus if the patient has 2° or 3° fusion, prior to any future biofeedback study, to get a better idea of the duction ranges.) Another reason may be that the isometric type of response which the biofeedback therapy requires can, in itself, increase duction ranges. Vaegan[19] found that his patients got increased vergence ranges after "five minutes of sustained effort at an angle halfway between the break and recovery points." He concluded that this improvement occurred because of the isometric nature of the exercise.

Although the mechanism may not be clear, it is apparent that auditory biofeedback strabismus therapy can be used to teach ocular alignment. The steps in learning this alignment appeared to be the same for all patients who did succeed in attaining an orthotropic posture with the biofeedback therapy. These steps paralleled the stages or landmarks described by Van Brocklin et al[12]: Stage 1) The patients "were able to bring their eyes into approximate alignment using the guidance of the biofeedback tone."[12] Stage 2) The patients could "align their eyes for short periods out of the biofeedback instrument"[12] but only with conscious effort. Stage 3) The patients could "sense when their eyes were not aligned"[12] and could align them without effort outside the biofeedback apparatus.

The two clinicians who were monitoring the biofeedback therapy noted that when the patients were in Stage 2 they were irritable. Such irritability has been noted by strabismus therapists[20] to occur when patients are attempting to reorganize their visual responses and therefore appears to be another landmark in therapy. Once the patients were in Stage 3 and could align their eyes without effort, the irritability disappeared.

When the patients were in Stage 1 and were able to turn the tone off, they all increased their efforts and motivation. None could explain what it was that they did to turn the tone off, but once they did it, they could do it again and again and this was very exciting to them.

It appears, then, that biofeedback is helpful in motivating a patient to work harder at his strabismus therapy. In fact, Letourneau[8] suggested that with biofeedback therapy in vision training, the rapport between the therapist and the patient would be eliminated as a major motivating factor. But in this study, the rapport between the two clinicians and the patients appeared to be an important factor in the patient's motivation. This was particularly apparent when one therapist had to switch with the other in the middle of the therapy program. In each case where this occurred, it took a few days for the new rapport to be established and on those days the patient's performance appeared to plateau. As Birnbaum[21] has indicated, the therapist provides the positive conditions for learning and is a "guide" leading the patient to "internalize changes in the visual process."[21] In order for the patient to accept the therapist as his guide, he must first learn to trust him, and that is done through establishing rapport.

Mann[22] indicated that a strabismic cure depends on the mental and physical health of the patient as well as family support. The present study appeared to support this statement. Case 4, who reported pain from orthodontia and dysmenorrhea, plateaued in her progress whenever these problems occurred. Progress was also at a standstill on days when she reported that her concern was high over two invalids whose care she was directly responsible for. In another example, Case 7 indicated that she felt she made more progress on Fridays than she did on Mondays because Fridays were more positive days for her. And Case 5 observed that although he had attained a functional cure, his eyes would sometimes deviate at the end of a hectic day. Family support at home to complete visual training exercises appeared to be a strong factor in the amount of progress that was made, and lack of family support appeared to be a strong factor in the lack of progress in certain skills for Cases 3 and 12. In contrast, patients who made rapid progress with home training had strong family support.

Nevertheless, biofeedback proved to be more motivating for these subjects with physical or mental stress and poor family support than did the conventional visual training needed to provide sensory re-adaptation to binocularity. Abadi[4] said that auditory biofeedback training for nystagmus was successful because it provided "modification of neural patterns in an appropriate direction," which is what both conventional training and auditory feedback provide. But it appears that auditory biofeedback is particularly helpful to a person who is trying to conquer visual problems and has not had satisfactory experience with visual feedback. Smith[24] found that auditory feedback is effective in both controlling and training eye position, and in some cases, is more effective than is visual feedback.

However, in this study it was found that although auditory biofeedback could teach gross motor alignment, it could not teach the fine alignment needed for stereopsis. Visual feedback had to be used to teach this alignment, and it was for this reason that anti-suppression training, if needed, was one of the first conventional visual therapy exercises given: the patient needed to see both images to superimpose one over the other for an exact alignment. It was not until the patient was able to superimpose the two images, in space, that he was able to also observe stereoscopic details in space. At this point he began to organize his stereoscopic skills and

exercises were given to augment organization of the stereofield.

It appears, then, that auditory biofeedback can be beneficial in strabismic visual therapy by providing the patient with skill in ocular motor alignment to a cosmetic posture. Used with conventional visual therapy, it can also help in effecting a functional cure: clear, single, comfortable binocular vision. This study also found that auditory biofeedback strabismus visual therapy is most effective for patients with a good prognosis for a functional cure who are highly motivated and are able to attend therapy sessions regularly.

SUGGESTIONS FOR FUTURE RESEARCH

A major question yet to be resolved about auditory biofeedback strabismus therapy using the Hirons and Yolton apparatus is what other changes are effected in the visual system besides a reduction of the objective angle. In order to answer this question, a visual exam must be given immediately before and after biofeedback therapy. (In the present study the patients were only tested at the beginning and end of the study so information about what happened to the visual system specifically as a result of biofeedback was not available.)

The visual testing should be extremely thorough and should include all those tests normally completed in a vision exam: case history, entrance tests (cover test, NPC, motilities, dominance, confrontation, monocular light fixation, reading distance, pupillary distance, and entrance acuities), tests for ocular health (ophthalmoscopy, biomicroscopy, external exam, tonometry, and pupillary responses), keratometry, dynamic and static retinoscopy, monocular and binocular subjective refraction to best visual acuity, horizontal and vertical phorias and ductions (near and far) if possible, monocular and binocular near cross cylinder, and monocular and binocular tests for accommodative amplitude and plus and minus lens to blur out and recovery.

In addition to these standard tests, the following tests should be given:

1. Specific strabismus case history: age and occurrence at onset of deviation; whether the deviation was constant, intermittent, or periodic and any changes in these conditions; whether the deviation was unilateral or alternating and any changes over the years from one to the other; previous treatments and results (lenses, occlusion, surgery, visual training), and the reason that the strabismic is seeking a cure.

2. Tests for accommodative amplitude, recovery, posturing, and facility: (near and far monocular and binocular cross cylinder, MEM and book retinoscopy, accommodative rock, and distance rock.)

3. Tests for vergence (vertical, horizontal, and cyclo): amplitude, recovery, posturing, and facility; duction ranges measured in the amblyoscope; Hirschberg test; deviation measured in the amblyoscope (subjective and objective); and prism rock.

4. Tests for comitancy: cover tests in all nine cardinal positions of gaze, subjective and objective.

5. Tests to calculate the AC/A AND CA/C (i.e. the interaction between accommodation and convergence) which include response/response ratios as well as stimulus/response ratios and tropia/distance relationships.

6. Visual fields: Autoplot and Brock Posture Board.

7. AO Vectographic tests (or others) for fixation disparity, suppression, and binocular refraction at near and at far, including use of diagnostic lenses to determine changes in posturing.

8. Tests for unification: degree of fusion in amblyoscope and card skills, performance on Randot, Stereofly, or Stereo Reindeer.

9. Tests for Binocular Visual Direction: Hering-Bielschowski After Image test with Ludlam variation*; luster with red and green glasses and a blank field; and luster in the stereoscope with the objective and subjective angle neutralized; Brock string response with red and green glasses and the effects of lenses and prisms on this response; Brock transferred after image combined with the Haidinger Brush; and Bagolini lenses.

10. Tests for Monocular Visual Direction: eccentric fixation or viewing (observation of center of grid on euthoscope, visuoscope, and ophthalmoscope and the patient's own response as to whether he feels he is looking right at the center of the grid), tests for eccentric fixation and macular integrity (Haidinger brushes, Maxwell spot), and tests for past-pointing.

With careful pre- and post-biofeedback testing, more information can be gathered on the effects of auditory biofeedback strabismus therapy on the visual system. At this point it is not known which of these visual factors auditory biofeedback is capable of changing. Eventually controlled clinical

* Ludlam, William M., Opt. 551, Optometry V notes, Pacific University College of Optometry, Spring 1980.

studies should be conducted on this method of attaining ocular alignment: these studies will aid in the understanding not only of the effects of auditory biofeedback but also in the understanding of the human visual system as it relates to strabismus.

SUMMARY

It was the purpose of this study to 1) explore the use of auditory biofeedback strabismus therapy when it was used prior to conventional visual therapy and 2) to determine if a functional cure was possible with such a strabismus therapy program. The results were that auditory biofeedback augments strabismus therapy and can help to effect a functional cure for those patients with a good prognosis for binocularity who can attend visual training sessions regularly. For those patients with a poor prognosis for binocularity, the biofeedback portion of the therapy program can teach ocular alignment or a decrease in the magnitude of the angle of deviation. But those patients with severe sensory anomolies such as anomolous angles, horror fusionis, and incomitancy had the same problems at both the beginning and the end of the study. Consequently, even with alignment or reduced angles, they did not attain binocularity.

Some surprises in this study were that duction ranges appeared to increase and vertical and cyclotropias appeared to be reduced along with the horizontal angles in some cases. (It appeared that the muscle actions necessary for horizontal alignment also affected the muscle responses for vertical and cyclo-posturing.) There is a definite need for future research into the specific visual effects of auditory biofeedback strabismus therapy. From the information gathered in this series of case studies, it appears that a controlled clinical study would be helpful so that the effects of auditory biofeedback strabismus therapy can be evaluated on a large, randomly selected population of strabismics.

APPENDIX I

Figures 1 - 4

FIGURE 1

PROCEDURES AND MATERIALS USED IN VISUAL THERAPY SESSIONS

Accommodative rock (+/- flipper)

Distance rock

a. Hart Chart

b. Letters on mirrors with polaroid glasses

Prism rock

Brock String

a. Tromboning with letters

b. Jumps

Red-Green glasses for suppression reduction

Baseball saccades

Saccadic Fixator

Septum saccades

Pegboard Rotator

BU and AN Series with Stereoscope

Tromboning of hand-held stereoscope with Theta Series and Binaco Sets A & B

Cheiroscope

Close pursuits with penlight or Tibetian Eye Chart

Montreal Chart for tracking and accommodative work

Marsden Ball

Directional Arrow Chart with metronome

Bar reader techniques

Key: ∠O= Objective angle in Δ
∠A= Angle of Anomoly in Δ
(∠O - ∠S)

FIGURE 2

SUBJECT DATA PRIOR TO TRAINING

Subject	Age	Type	Prev. VT	Prev. Surgery	Initial Posture ∠O ∠A	Sensory Anomolies	BI & BO Ductions	Unification	Refractive Error	V.A.
1	10	Comitant Altern. Diverg. Excess Interm. ExoT. Hypertropia	0	0	Lateral BI: 22Δ @ 20' 0 12Δ @ 16" 0 Vertical: 2Δ Rt. Hyper	suppression	not measurable	3° fusion (amblyoscope)	+.50 OD +.25 OS	20/15 20/20
2	10	Comitant Interm. Altern. ExoT.	0	0	Lateral BI: 30Δ @ 20' 0 30Δ @ 16" 0	suppression	not measurable	3° fusion (Amblyoscope) 20" (Randot)	+.50-.25x135 +.25-.25x090	20/20 20/20
3	7	Comitant Diverg. Excess Interm. Alternating Exotrope	0	0	Lateral BI: 25Δ @ 20' 0 8Δ @ 16" 0	"	"	3° fusion (Amblyoscope)	-.25-.25x090 -.25-.25x090	20/15 20/20
4	23	Comitant Interm. Unilat. Right ExoT.	0	0	Lateral BI: 16Δ @ 20' 0 16Δ @ 16" 0	"	BO 16/2Δ BI 5/2Δ @ 20' BO 24/3Δ BI 13/6Δ 2 16"	3° fusion (Amblyoscope)	-.50-.50x130 -.25-.25x105	$20/20^{+1}$ $20/15^{-1}$

Figure 2 (p. 2)

SUBJECT DATA PRIOR TO TRAINING

Key: ∠O= Objective Angle in Δ
∠A= Angle of anomoly in Δ
(∠O - ∠S)

Subject	Age	Type	Prev. VT	Prev. Surgery	Initial Posture ∠O	Initial Posture ∠A	Sensory Anomolies	BI & BO Ductions	Unification	Refractive Error	Aided V.A.
5	39	Comitant Interm. Altern. ExoT.	8 Wks. Biofeed-back VT	0	Lateral BI: 26Δ-14Δ @ 20'	0	suppression	not measur-able	2° fusion (Amblyoscope)	-.75-.50x115 -.50-.50x075	20/20 20/20
					26Δ-14Δ @ 16"	0					
6	11	Comitant Unilat. Periodic Left ExoT. & HyperT.	7 Wks. Trad. Strab. & 4 Wks. Ambly. VT	0	Lateral BI: 25Δ @ 20'	0	suppression; eccentric fixation; amblyopia; aniseikonia	"	1° fusion (Amblyoscope)	-.25-.25x090 +3.50-.25x090	$20/20^{+1}$ $20/60^{+2}$
					20Δ @ 16"	0					
					Vertical: 8Δ Left HyperT.						
7	28	Comitant Left Unilat. ExoT. & HyperT. (Intermit.)	14 Wks. Biofeed-back VT	0	Lateral BI: 55Δ-20Δ @ 20'	0	suppression; cover nystagmus OS poor fixation OS high myopia and deep amblyopia OS (SBVA 6/200)	"	1° fusion (Amblyoscope)	-7.75-.25x030 -18.00 sphere	$20/20^{-4}$ 6/200
					45Δ-20Δ @ 16"	0					
					Vertical: 10Δ-20Δ Rt. Hyper.						
8	9	Noncomi-tant Constant Unilat. Rt. ExoT. (V Synd.) HyperT. CycloT.	15 Wks. Trad. VT	0	Lateral BI: 40Δ-30Δ @ 20'	0	suppression; organic amblyopia	"	3° fusion (Amblyoscope)	+.50 sphere +.25 sphere	20/30 20/15
					40Δ-30Δ @ 16"	0					
					Vertical: 2Δ-7Δ Left Hyper, 24° ExcycloT.						

Figure 2 (p. 3)

SUBJECT DATA PRIOR TO TRAINING

Subject	Age	Type	Prev. VT	Prev. Surgery	Initial Posture ∠O	Initial Posture ∠A	Sensory Anomolies	BI & BO Ductions	Unification	Refractive Error	Aided V.A.
9	45	Comitant Constant Trad. Altern. VT @ ExoT. & ages 6-8 HyperT.		two	LateralBI: 55Δ @ 20' 16Δ; 55Δ @ 16" 16Δ; Vertical: 1-2Δ Left Hyper. (transient)		suppression; ARC; Horror Fusionis	not measurable	1° fusion (Amblyoscope)	+3.25-1.00x78; +3.00-0.25x90; +1.75 add OU	20/15; 20/20; 20/20 OU
10	15	Noncomitant 22Wks. Altern. Trad. Interm. VT EsoT., Double HyperT. & CycloT.		two	Lateral BO: 25-18Δ @ 20' 18Δ; 25-18Δ @ 16" 18Δ; Vertical: 20Δ left hyper. 10Δ right hyper. @ 16 inches; 14Δ Left hyper & 10Δ right hyper @ 20 feet; 3°left Cyclo		suppression; Unsteady fixation; Cover Nystagmus	"	2° fusion (Amblyoscope)	+.50sphere; +.50-.75x20	20/15; 20/20
11	42	Incomitant Constant 0 Rt. Unilat. EsoT., CycloT., & HypoT.		two	Lateral BO: 14Δ @ 20' 31Δ; 14Δ @ 16" 31Δ; Vertical: 1-7Δ Left Hyper. 6° Rt. Cyclotropia		constant diplopia; amblyopia OD; Horror Fusionis; Limit. of Gaze	"	1° fusion (Amblyoscope)	-.75-1.25x90; -1.75-0.50x80	20/200; 20/20-5
12	11	Comitant Constant 20 Wks, Unilat. Trad. Rt. EsoT.		0	Lateral BO: 80Δ @ 20' *; 80Δ @ 16" *		suppression; deep amblyopia OD eccentric fixation OD	"	*	+2.50 sphere; +1.00 sphere	20/200; 20/20

KEY: ∠O= Obj. angle of deviation in Δ

∠A= Angle of anomoly (∠O- ∠S) in Δ

* Unreliable responses

∠O = Objective Angle in prism diopt. (Δ)
∠A = Angle of anomoly in prism diopt. (Δ)
(∠O - ∠S)

FIGURE 3
RESULTS OF TOTAL TRAINING PROGRAM

Case [Type]	Initial Posture ∠O	∠A	Final Posture ∠O	∠A	Present Sensory Anomolies	Present Unification	Present BI & BO Ductions in Δ	Present Refractive Error	Bio-feedback Hrs.	Pass Stress Field Tests	Trad. VT Hrs.	Met Flom's Criteria	Time in Program
1 [Comitant Altern. Diverg. Excess ExoT. & HyperT. (Intermittent)]	22Δ @ 20' 12Δ @ 16" 2 Rt. HyperT.	0 0	Ø @ 20' Ø @ 16" no vert.	0 0	none	3° fusion (Amblyos.) 20" stereo (Randot)	BO 24/16 BI 20/18 @ 20' BO 24/18 BI 26/19 @ 16"	+.25sph. OD +.25-.25x20 OS	21	yes	6 office 5 home	yes	6 weeks
2 [Comitant Interm. Altern. ExoT.]	30Δ @ 20' 30Δ @ 16"	0 0	Ø @ 20' Ø @ 16"	0 0	none	3° fusion (Amblyos.) 20" stereo (Randot)	BO 20/12 BI 18/12 @ 20' BO 26/12 BI 30/24 @ 16"	+1.25-.50 x80 OD +1.00-.50 x90 OS	27	yes	9 office 12 1/2 home	yes	10 weeks
3 [Comitant Interm. Altern. Diverg. Excess ExoT.]	25Δ @ 20' 8Δ @ 16"	0 0	Ø @ 20' Ø @ 16"	0 0	none	3° fusion (Amblyos.) 20" stereo (Randot)	BO 22/10 BI 24/18 @ 20' BO 32/31 BI 16/18 @ 16"	+.25 sph. OD +.25 sph. OS	9	yes	14 office	yes	9 weeks
4 [Comitant Interm. Unilat. Rt. ExoT.]	16Δ @ 20' 16Δ @ 16"	0 0	4 @ 20' 4 @ 16"	0 0	suppression	3° fusion (Amblyos.) 200" stereo (Randot)	BO 16/2 BI 5/2 @ 20' BO 24/3 BI 13/6 @ 16"	-.50-.50 x130 OD -.25-.25 x105 OS	15	1st three	0	no	4 months
5 [Comitant Interm. Altern. ExoT.]	26-14Δ @ 20' 26-14Δ @ 16"	0 0	Ø @ 20' Ø @ 16"	0 0	none	3° fusion (Amblyos.) 20" stereo (Randot)	BO 22/12 BI 18/12 @ 20' BO 12/6 BI 28/18 @ 16"	-.75-.50 x120 OD -.75-.75 x060 OS	9	yes	13 office 15 home	yes	15 weeks

Key: ∠O= Objective Angle in prism diopt.
∠A= Angle of anomoly in prism diopt.(
(∠O -∠S)

FIGURE 3 (p. 2)

RESULTS OF TOTAL TRAINING PROGRAM

Case [Type]	Initial Posture ∠O ∠A	Final Posture ∠O ∠A	Present Sensory Anomolies	Present Unification	Present BI & BO Ductions	Present Refractive Error	Bio-feedback Hrs.	Pass Stress Field Tests	Trad. VT Hrs.	Met Flom's Criteria	Time i Progra
6	25Δ @ 20' 0 20Δ @ 16" 0 8Δ Lt. HyperT. [Comitant Unilat. Left Periodic ExoT. & HyperT.]	Ø @ 20' 0 Ø @ 16" 0 1Δ Rt. Hyperphoria	slight & variable eccentric fixation @ 20' but not @ 16"	3°fusion (Amblyos.) 30" stereo (Randot)	BO 8/6 BI 16/14 @ 20' BO 10/8 BI 8/8 @ 16"	+.50-.50 x88 OD +3.50 sph.OS	5	yes	46 office 15 home	yes	20 wk
7	55-20Δ @ 20' 0 45-20Δ @ 16" 0 10-20Δ Rt. Hyper [Comitant Interm. Left Unilat. ExoT. & HyperT.]	55-ØΔ @ 20' 0 45-ØΔ @ 16" 0 10-ØΔ Vert.	suppression poor fixation Amblyopia (OS 20/120) cover nystagmus	3°fusion (Amblyos.) no measurable stereo	not measurable	-7.75-.25 x30 OD -18.00sph OS	28	1st test only	38 home	no	24 wks
8	40-30Δ @ 20' 0 40-30Δ @ 16" 0 2-7Δ Lt. Hyper 24° Rt. Encyclo. [Non-comitant constant Unilat. Rt. ExoT., HyperT., & CycloT.]	35Δ @ 20' 0 25Δ @ 20" 0 14Δ @ 10" Ø @ 5"	suppression Organic Amblyopia (OD 20/50)	3°fusion (Amblyos.)	"	+.50sph OD +.25sph OS	25	no	27 home	no	12 wks
9	55Δ @ 20' 16 55Δ @ 16" 16 1-2Δ Lt. Hyper Subjective: 39Δ @ 20' 39Δ @ 16" [Comitant constant altern. ExoT. & HyperT.]	55Δ @ 20' 16 55Δ @ 16" 16	suppression ARC Horror Fusionis	1°fusion (Amblyos.)	"	+3.25-1.00 x78 OD +3.00-.25 x90 OS	17	no	0	no	4 wks.

Key: ∠O=Objective Angle in prism diopt. (Δ)
∠A= Angle of Anomoly in prism diopt. (Δ)
(∠O -∠S)

FIGURE 3 (p. 3)

RESULTS OF TOTAL TRAINING PROGRAM

Case [Type]	Initial Posture ∠O	Initial Posture ∠A	Final Posture ∠O	Final Posture ∠A	Present Sensory Anomolies	Present Unification	Present BI & BO Dustions	Present Refractive Error	Bio-feedback Hrs.	Pass Stress Field Tests	Trad. VT Hrs.	Met Flom's Criteria	Time in Program
10	25-18Δ@ 20'	18Δ	Ø @ 20'	0	He left study due to an injury. No post-program data available except for the last cover test entry following the last biofeedback session.				4	no	0	no	1 week
	25-18Δ@ 16"	18Δ	Ø @ 16"	0									
20Δ l. & 10Δ r.hyper @ 16"		2Δ l.hyp.	4Δ Rt. Hyper & 6Δ Lt. Hyper @ 16"										
[14Δ l. & 10Δ r.hyper @20' Non-comitant altern. interm. EsoT., Double HyperT., & 3° Left CycloT.]			6Δ r. & 8Δ l.hyper @ 20'										
11	14Δ@ 20'	31	Ø @ 20'	45	Amblyopia OD Constant diplopia Horror fusionis Limit. of gaze OD	1° fusion (Amblyos.)	not measurable	-.75-1.25 x90 OD -1.75-.50 x80 OS	20	1st test only	5 office 12 home	no	10 weeks
	14Δ@ 16"	31	Ø @ 16"	45									
	1-7Δ Lt. Hyper 6° Rt. EncycloT. Subjective: 45Δ @ 20' & 16"		1/2-3Δ Lt Hyper 0-6° Encyclo Subjective: 45Δ @ 20' & 16"										
(Both subj. with above hyper & cyclotropia) [Incomitant constant Rt. EsoT., HyperT., CycloT.]													
12	80Δ@ 20'	*	65Δ@ 20'	*	Suppression Deep Eccentric fixation Amblyopia (OD 20/100)	2° fusion (Amblyos.)	"	+2.50 sph +1.00 sph	20	no	10 office	no	5 months
	80Δ@ 16"	*	65Δ@ 16"	*									
[Comitant constant unilat. Rt. EsoT.]													

* Unreliable responses

KEY: ∠O= Objective angle of deviation in prism diopters
∠A= Angle of anomoly in prism diopters

Figure 4

Graphs of objective measure of lateral deviation.

Symbols:

○ Prior to Biofeedback session @ distance

● Post-Biofeedback @ distance

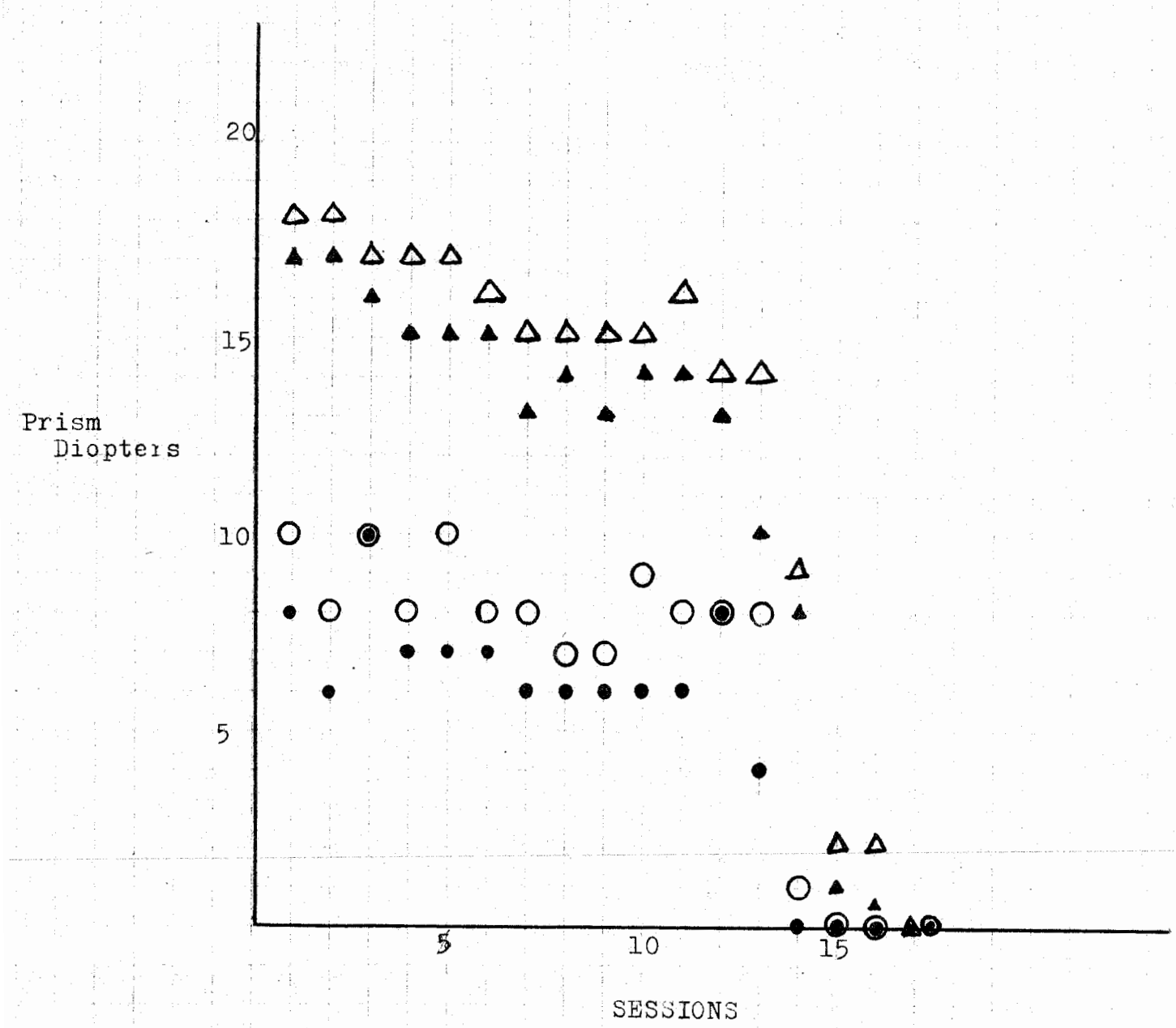
△ Prior to Biofeedback session @ near

▲ Post-Biofeedback @ near

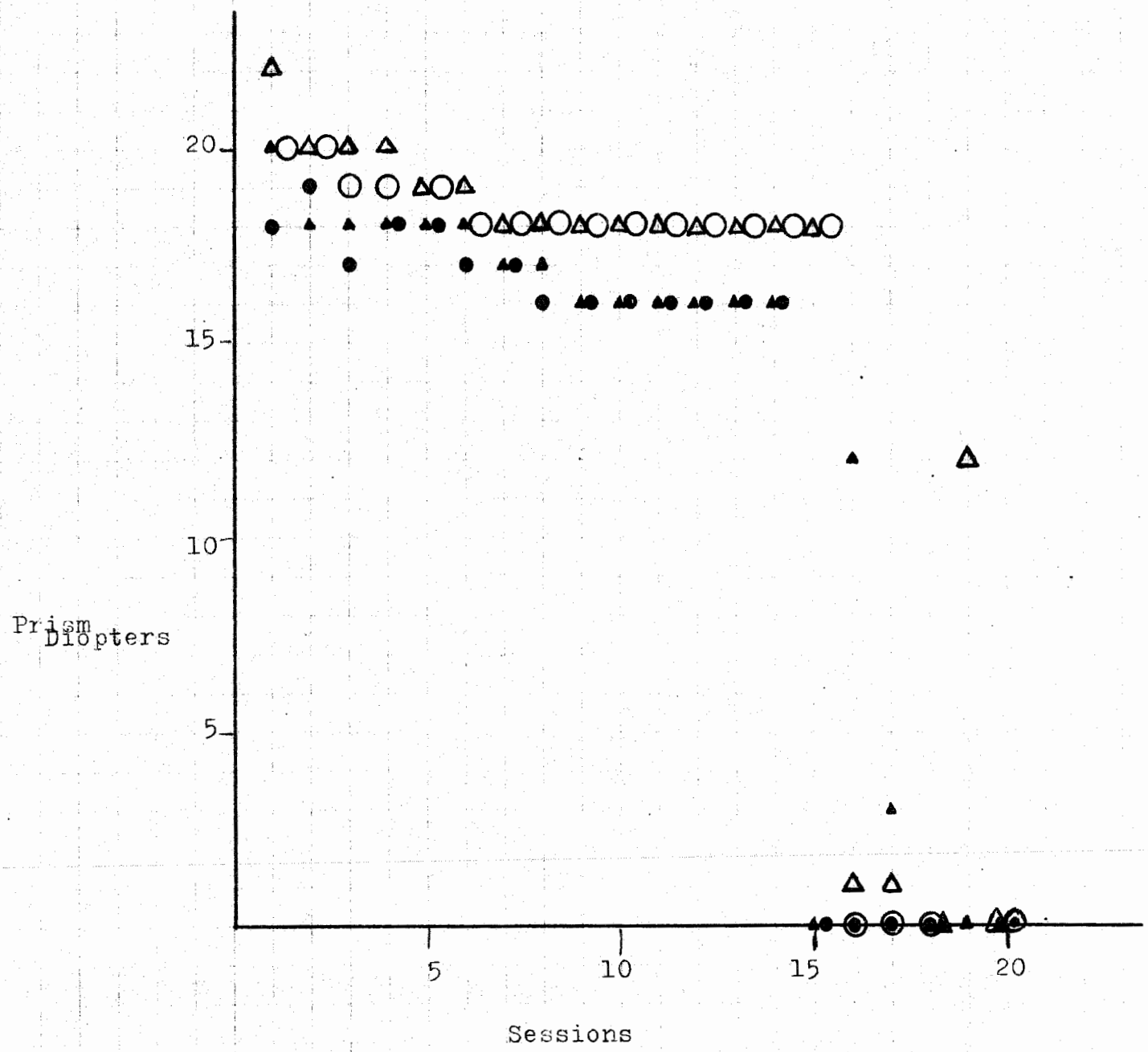
* Data may vary from other measures of posture due to being taken with biofeedback apparatus in place.

HORIZONTAL COMPONENT OF STRABISMIC ANGLE

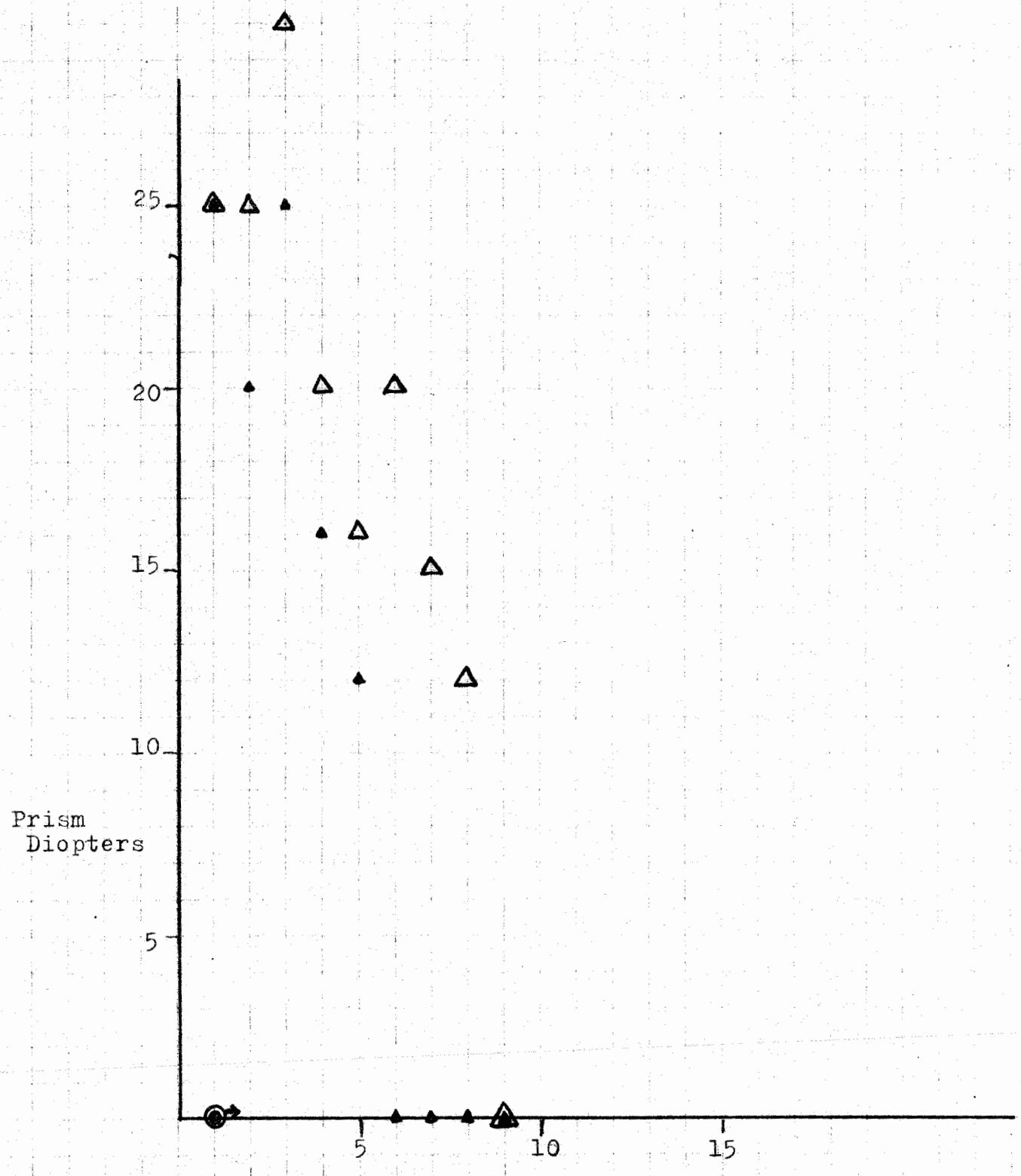
#1



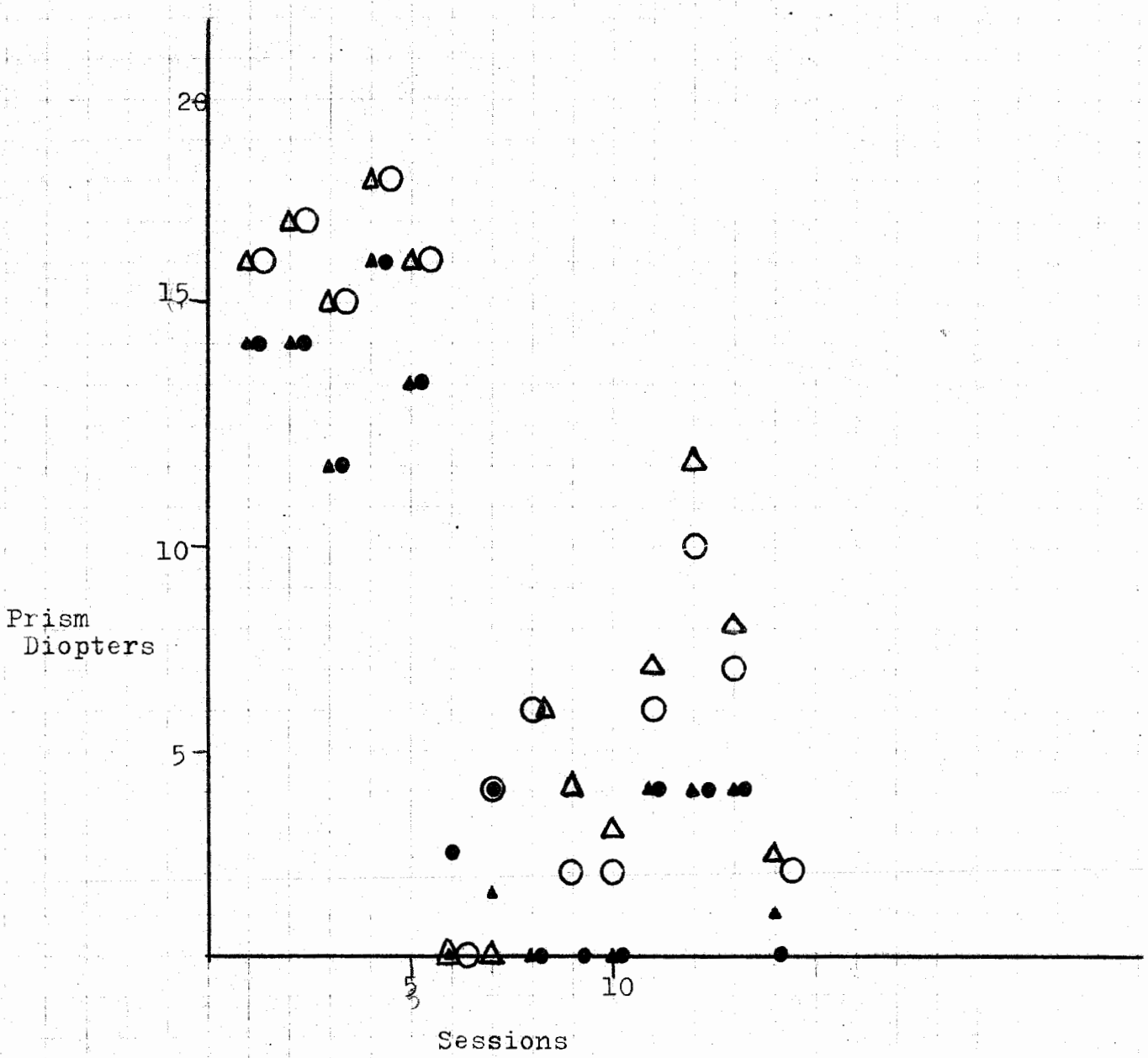
#2

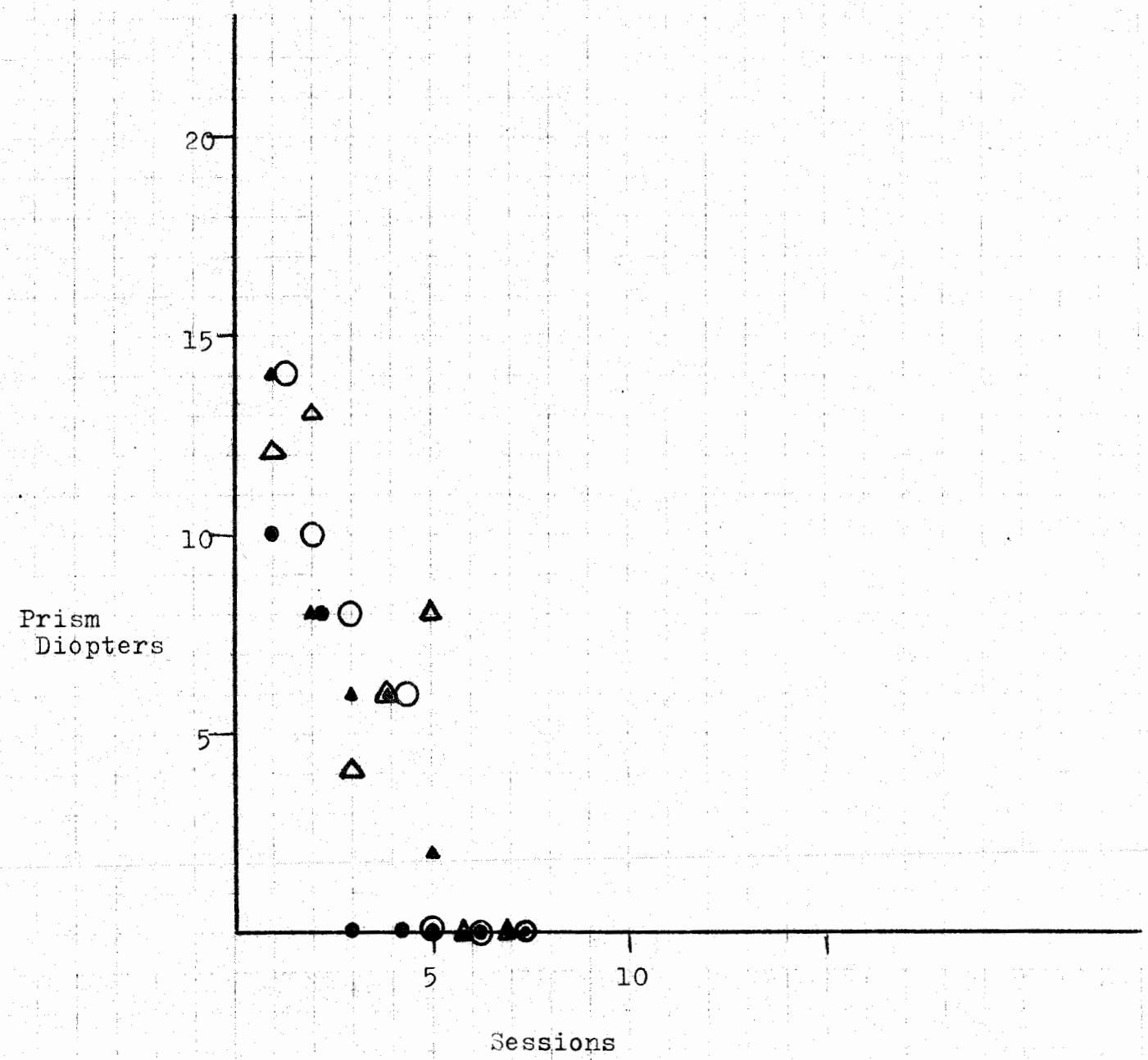


#3

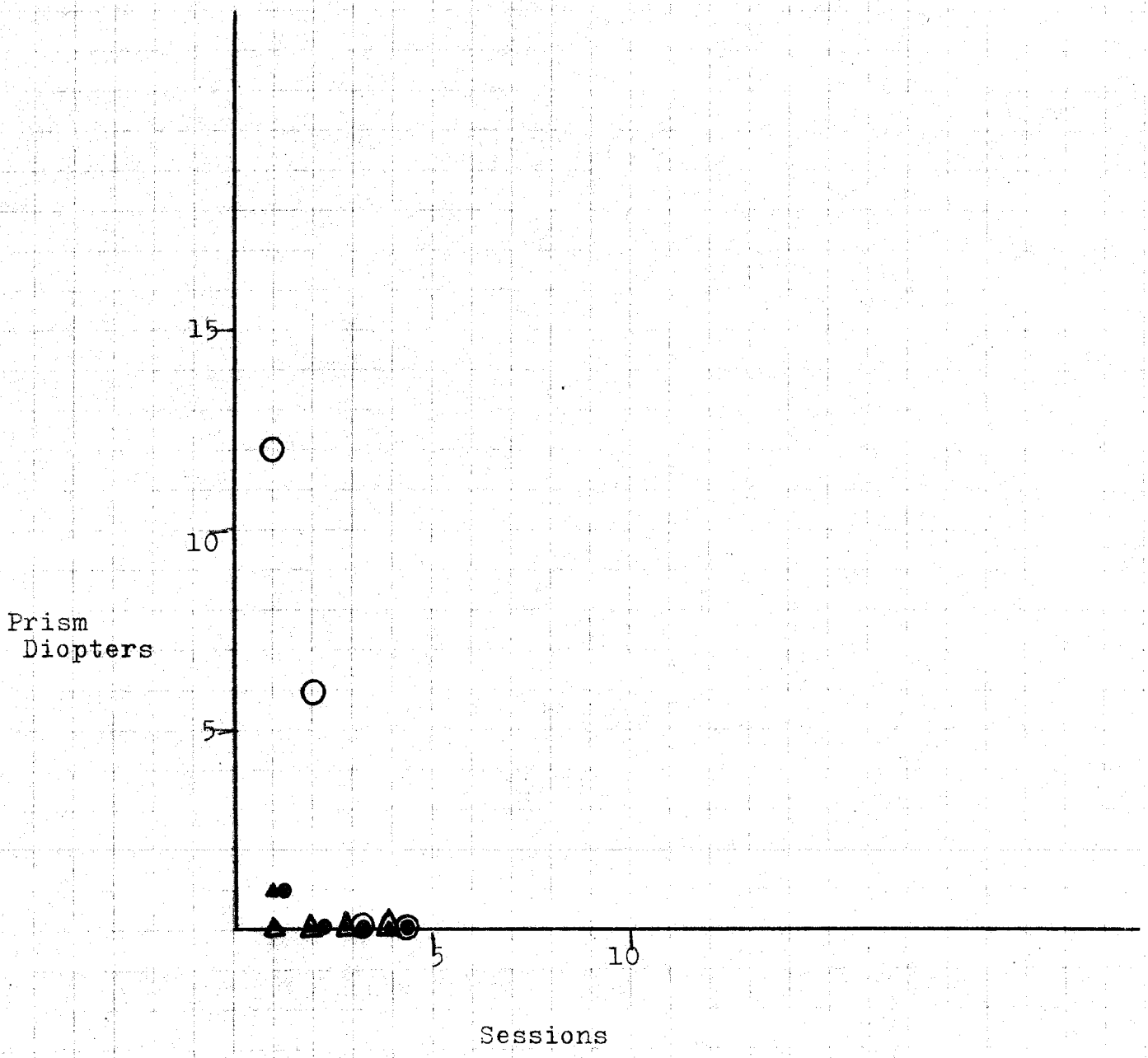


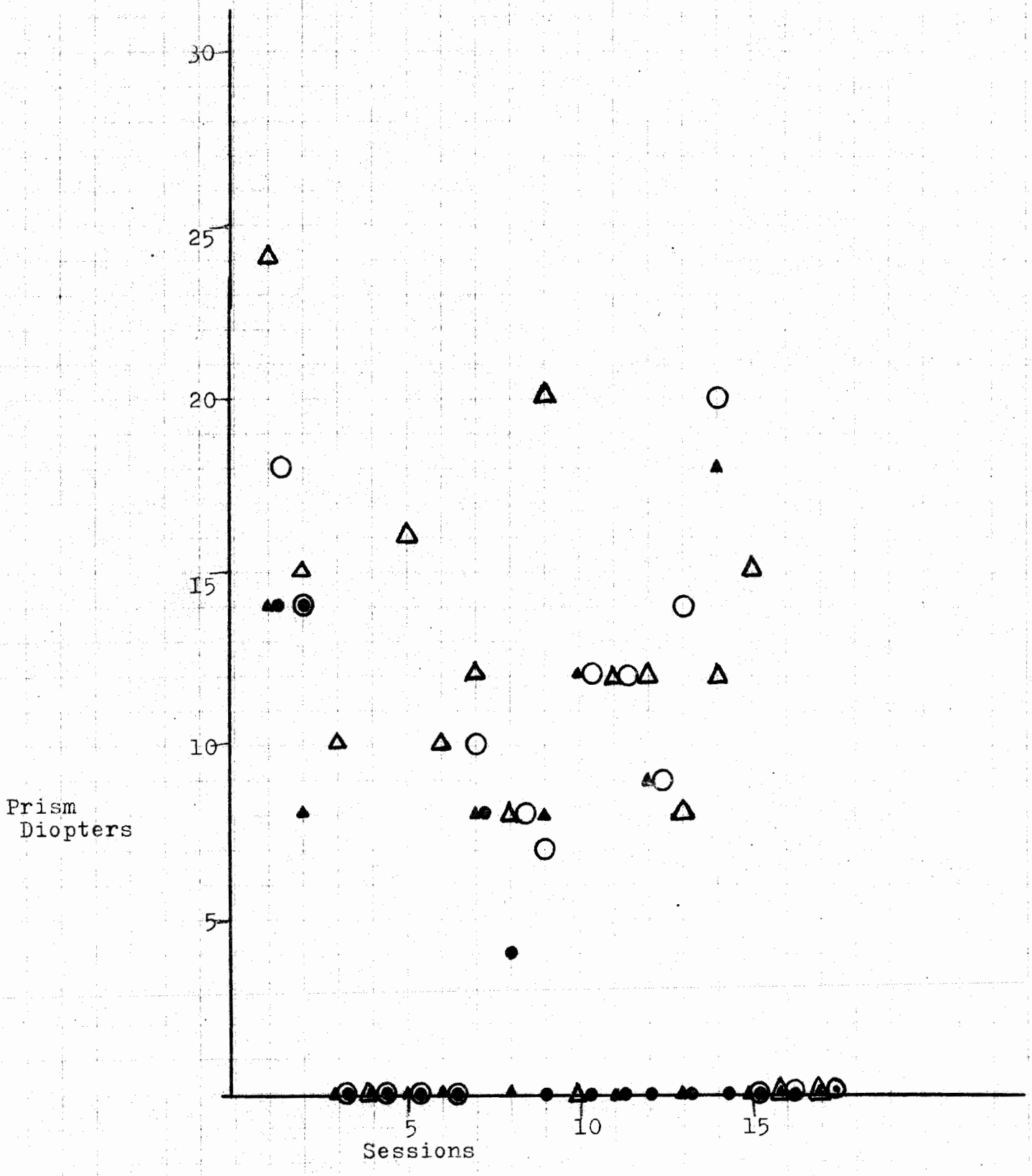
#4

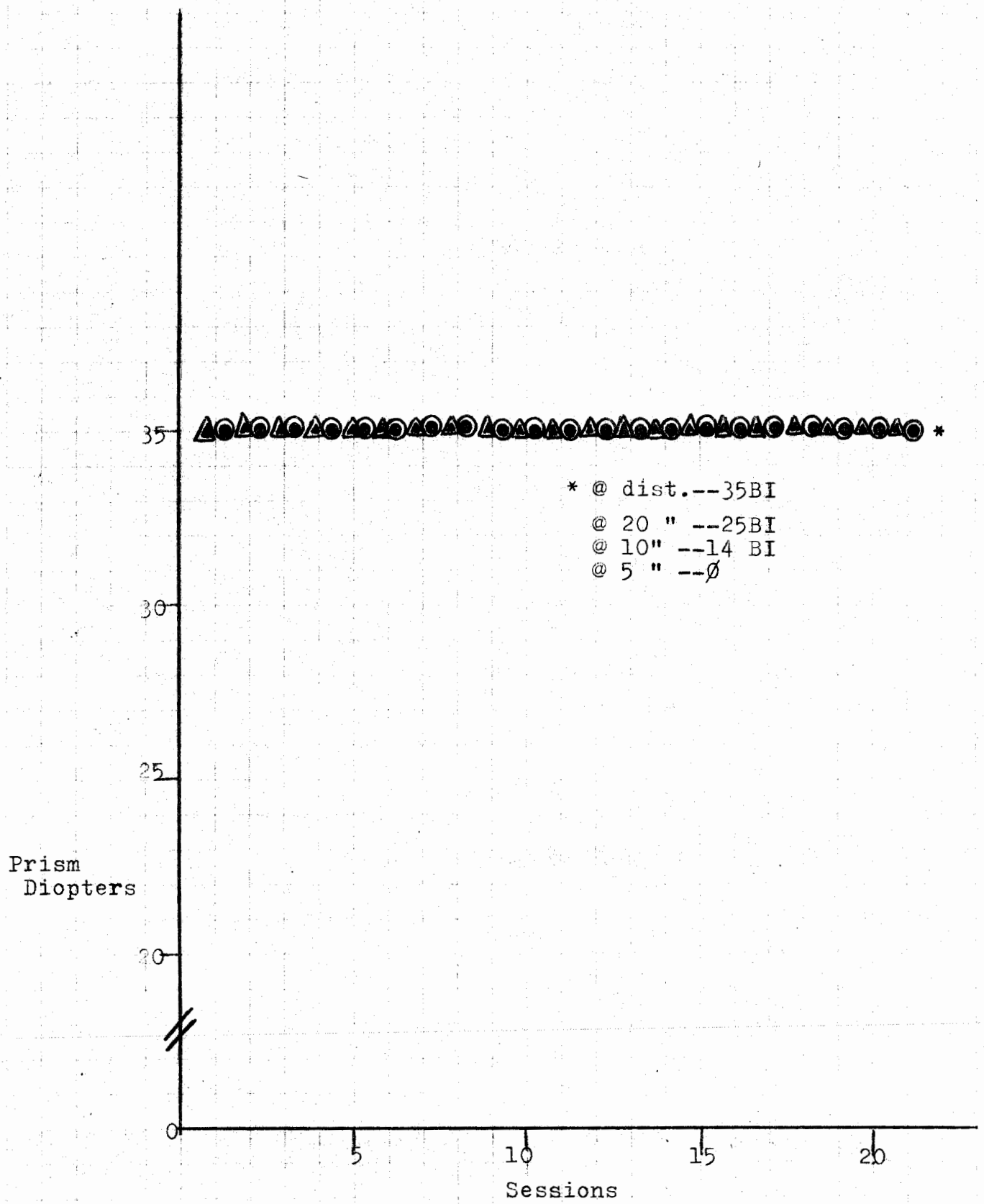



20
15
10
5
Prism
Diopters
5
10
Sessions

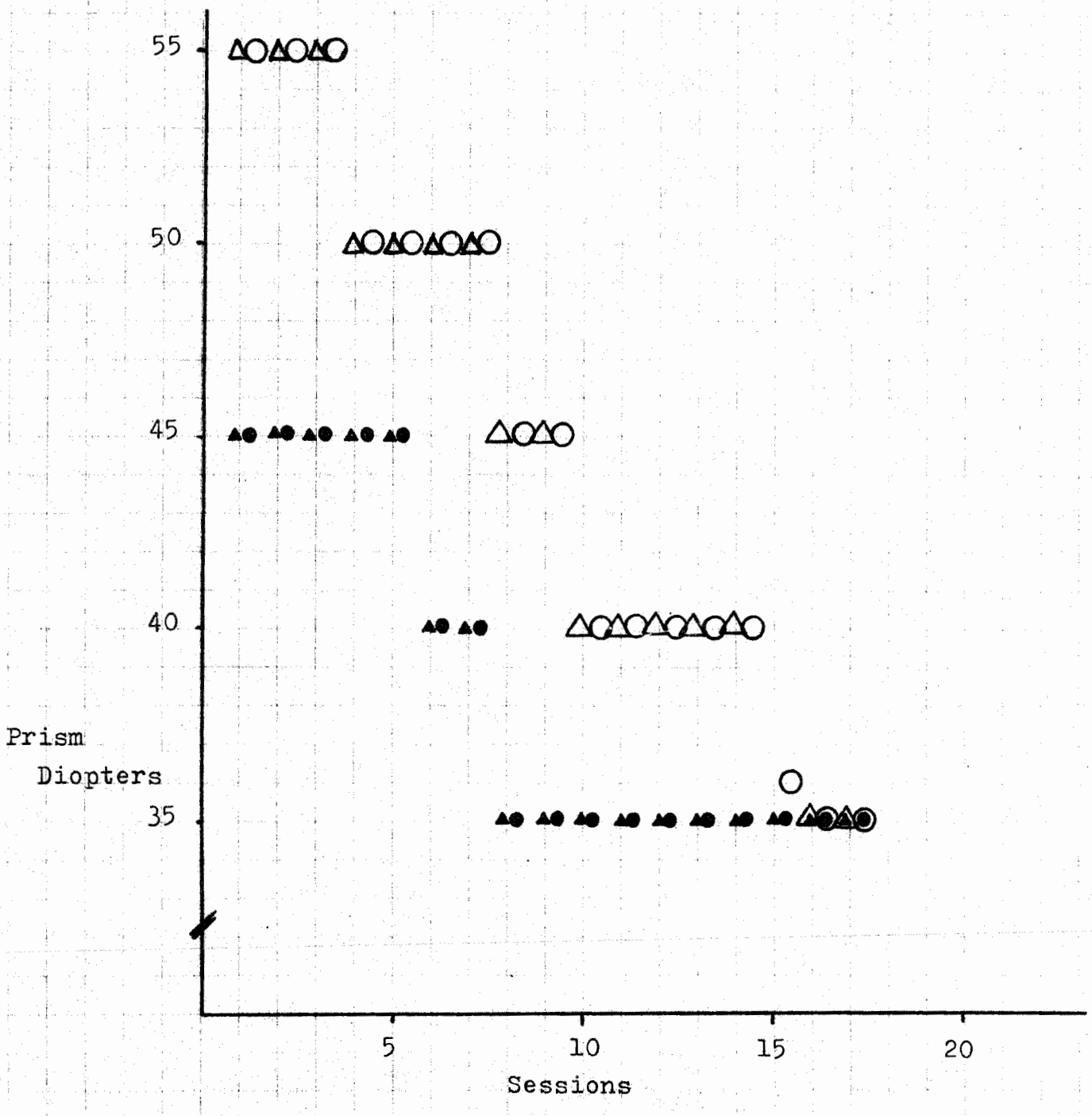
#6



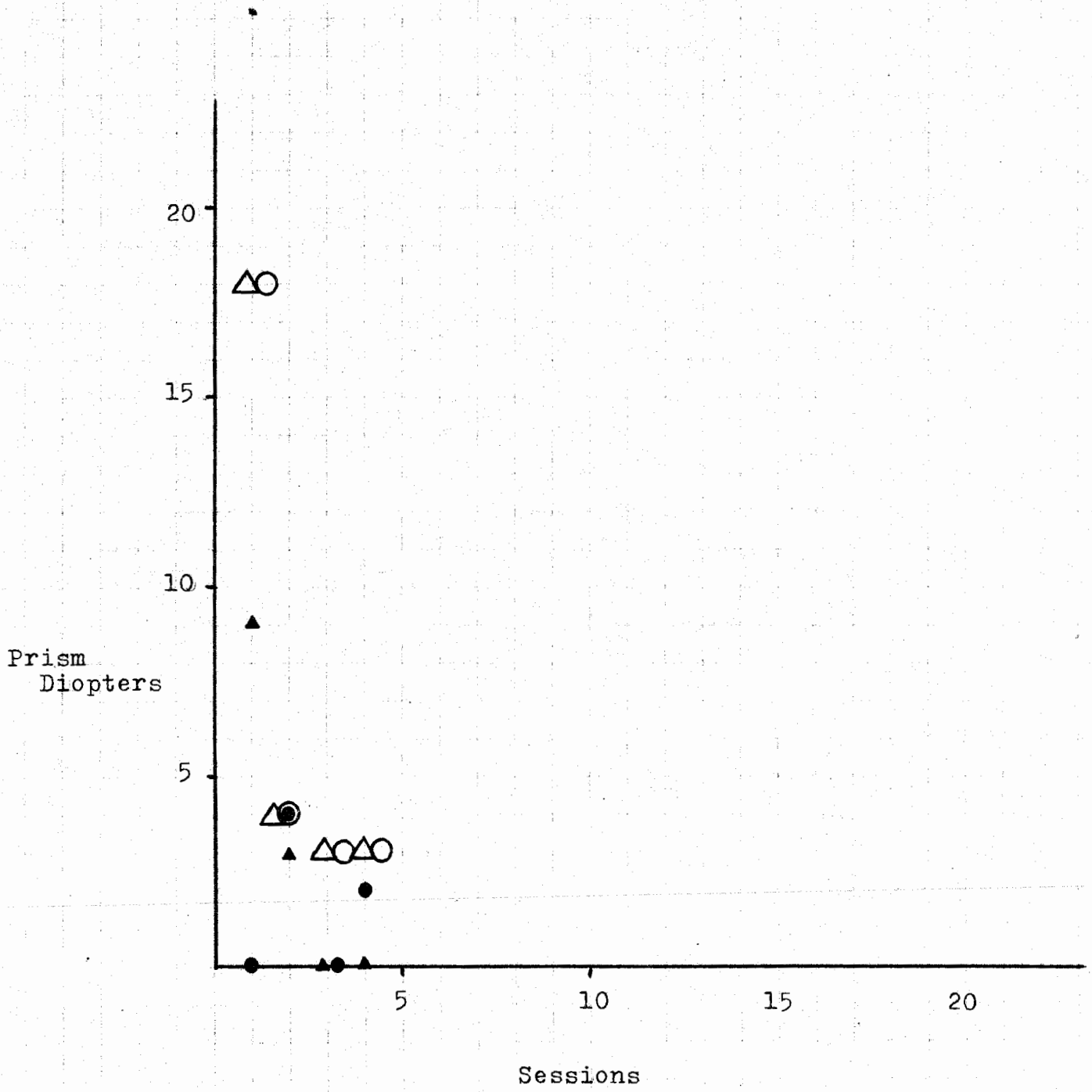

30
25
20
15
10
5
Prism Diopters
5
10
15
Sessions


35
30
25
20
0
Prism
Diopters
5
10
15
20
Sessions
* @ dist.--35BI
@ 20 " --25BI
@ 10" --14 BI
@ 5 " --Ø

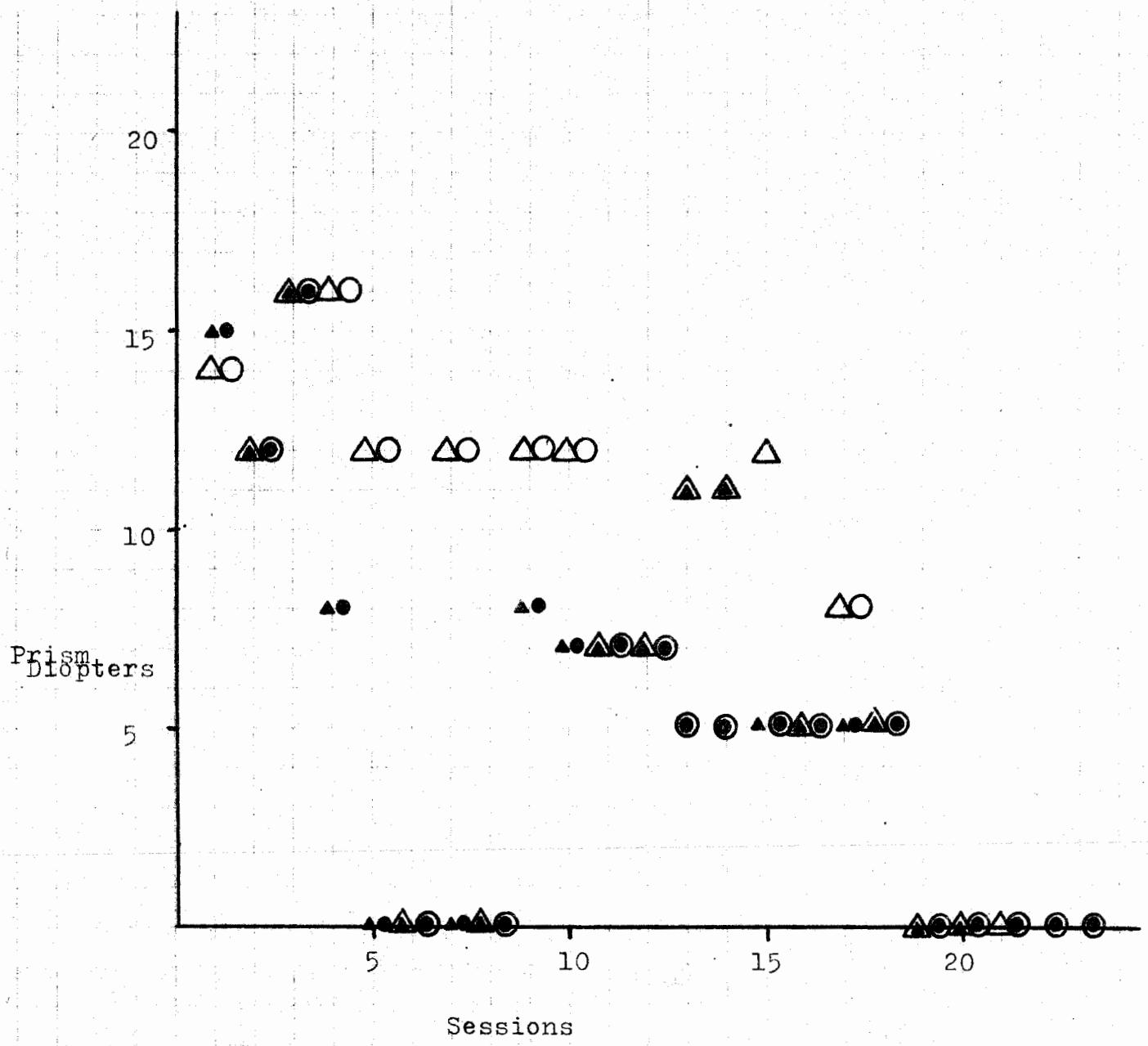
#9



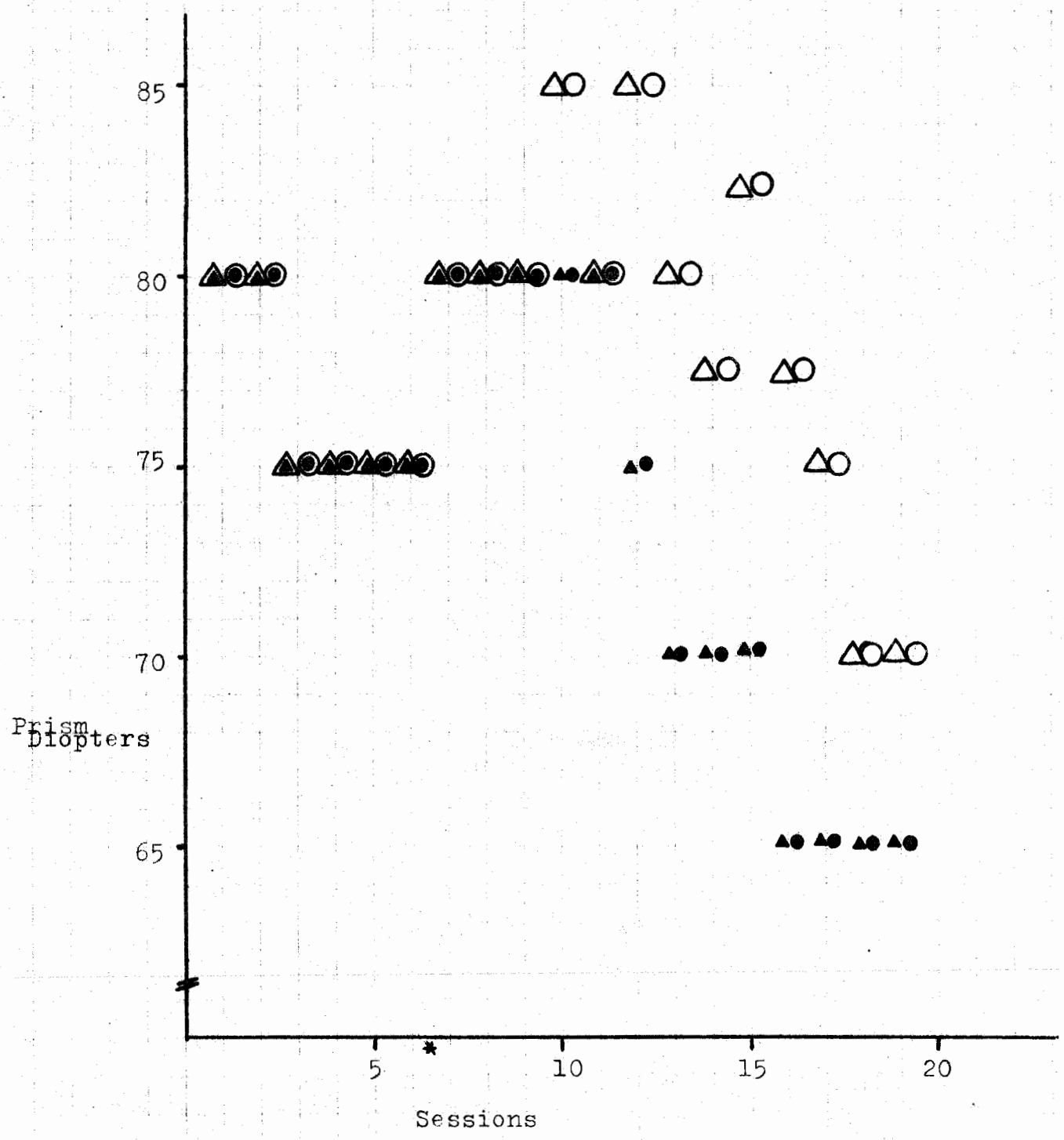
#10



#11



#12


85
80
75
70
65
Prism
Diopters
5
10
15
20
Sessions
* Intern change

APPENDIX II FORMS

STRABISMUS ANALYSIS

Name_____ Date_____

Address_____

Birthdate_____ Age_____ Grade___ Parent's Name_____

CASE HISTORY

1. Age at onset_____ (start of school) (18-36 mo.) (birth)(sudden)
2. Any unusual occurrence_____
3. Has deviation always been constant:(No) (Yes)_____
4. Has same eye always been deviated:(No) (Yes) (alternates)_____
5. If intermittent, when it occurs:(PM) (AM) (after close work)_____
6. Previous Exams or Treatment Results:(Lenses) (Occlusion) (Surgery) (VT)_____

   where:_____
7. Strabismus/Amblyopia present in immediate family:(Yes)(No) Who:_____

ACUITY (Letters) (C) (Pictures)

	FAR OD	OS	OU	NEAR OD	OS	OU	Habitual Dx OD	OS	OU
1. unaided	___	___	___	___	___	___	___	___	___
	@	@	@	@16"	@16"	@16"	@	@	@
2. with RX	___	___	___	___	___	___	___	___	___
	@	@	@	@16"	@16"	@16"	@	@	@
3. pinhole	___	___	___	___	___	___			
4. single letter	___	___	___	___	___	___	___	___	___
	@	@	@	@	@	@	@	@	@

COVER TEST	Alternate Obj.	Subj.	Unilateral Obj.	Subj.		Alternate Obj.	Subj	Unilateral Obj.	Subj.
Primary Gaze					Left Gaze				
Far	___	___	___	___	Far	___	___	___	___
Near	___	___	___	___		___	___	___	___
Superior Gaze					Right Gaze				
Far	___	___	___	___	Far	___	___	___	___
Near	___	___	___	___	Near	___	___	___	___
Inferior Gaze					Primary				
Far	___	___	___	___	Habitual				
Near	___	___	___	___	Rdg. Dx	___	___	___	___

NPC	First Trial Obj.	Subj.	Second Trial Obj.	Subj.	Third Trial Obj.	Subj.	Comments re: improvement or breakdown
Break	____	____	____	____	____	____	_____
Recov.	____	____	____	____	____	____	_____

MOTOR FIELDS (VERSIONS) _____ ROTATIONS _____ SACCADICS Horiz. ____ Vert. ____ Oblique ____

OD _____ _____

OS _____ _____

OU _____ _____

Comments: _____

DONDER'S ACCOMMODATIVE AMPLITUDE: BREAK/RECOVERY OD___ OS___ OU___

DOMINANT EYE: (right) (left) DOMINANT HAND: (right) (left)

MONOCULAR LIGHT FIXATION

OD_____ OS_____ (Equal) (Unequal) (Steady) (Unsteady)

HIRSCHBERG

OD___ mm OS___ mm (Equal) (Unequal) (Steady) (Unsteady)

OD_____ OS_____ (KRIMSKY)

PD Near_____ Dx_____

PUPILLARY REFLEXES	Yes	No
Direct	___	___
Consensual	___	___
Accommodative	___	___

OPHTHALMOSCOPY Fixation of grid center

OD (Normal) (Path) (Central) (Nasal) (Temp.) (Sup.) (Inf.)_____

OS (Normal) (Path) (Central) (Nasal) (Temp.) (Sup.) (Inf.)_____

Distinguishing characteristics: _____

_____

KERATOMETRY Monoc. Nystagmus: (YES) (NO) Which Eye: (RIGHT) (LEFT)

OD_____D, _____D @_____ Javal's Rule _____x_____

OS_____D, _____D @_____ Javal's Rule _____x_____

REFRACTION	OD	VA	OS	VA	OU	VA
Retinosocopy	___	___	___	___	___	___
7 monoc.	___	___	___	___	___	___
7 binoc.	___	___	___	___	___	___
7A binoc.	___	___	___	___	___	___
NEAR X/CYL						
mon.	___	___	___	___	___	___ phoria
bin.	___	___	___	___	___	___ phoria

other:

R/G OD____

OS____

FAR X/CYL

OD____

OS____

FUSION: (Keystone Cards) (Amblyoscope) (Other;_____)
Simultaneous Perception (YES) (NO) (FAR) (NEAR)
Superimposition (YES) (NO) (FAR) (NEAR)
Stereopsis (YES) (NO) (FAR) (NEAR) _____arc sec
Comments:_____

ANGLE OF DEVIATION: (Amblyoscope) (Troposcope)

OBJECTIVE

FAR: ESO EXO ALT. _____D PHORIA TROPIA HYPER_____OD OS
NEAR: ESO EXO ALT. _____D PHORIA TROPIA HYPER_____OD OS

SUBJECTIVE

FAR: ESO EXO ALT. _____D PHORIA TROPIA HYPER_____OD OS
NEAR: ESO EXO ALT. _____D PHORIA TROPIA HYPER_____OD OS

ARC TESTS

Bielschowski After Image:
Eyes Closed: Eyes Open: Ludlum variation:

R/G glasses (Luster) (Split field)

Brock String with R/G glasses:

Other:

HUMAN SUBJECT INFORMED CONSENT RELEASE FORM

1. Institution
   A. Title of Project: Evaluation of Biofeedback-Enhanced Visual Training for Exotropes
   B. Principal Investigators: Marlene Inverso and Tricia Larsen
   C. Advisors: Dr.'s Robert Yolton, Donald Schuman, and Harold Haynes
   D. Location: Pacific University College of Optometry, Forest Grove, Oregon 97116
   E. Date: 1980-1981

2. Description of Project
   This project will provide auditory biofeedback treatment prior to traditional visual training for strabismus therapy. The auditory biofeedback treatment will involve having the patient wear a trial frame on which are mounted infrared sensors directed toward the limbus of each eye. The output of these sensors will indicate the deviation of each eye by a variation of pitch. The patient will learn to straighten his or her eyes by keeping the tone low or silent. After the patient has learned to keep both eyes straight, he or she will undergo traditional visual training to integrate the sensory and motor responses so that straight eyes will become the habitual eye posture for that patient.

3. Description of Risks
   The biofeedback equipment is modern, sophisticated, and like electronic devices with minimal risks used in health professional environments. Some patients have found that learning to move their eyes to a straight-ahead position may make them see double, have headaches, or feel uneasy initially. However, unless there is a case of intractable diplopia, these feelings should go away as the therapy continues and their eyes learn the straight-ahead position.(Our pretesting is designed to screen out patients who will have intractable diplopia, so this risk is minimal.)

4. Description of Benefits
   This study will serve to increase the basic understanding of the way the nervous system controls eye position and to provide more information on biofeedback as a more efficient alternate to traditional visual training used to straighten deviated eyes. The patient, if successful with this training, will have the benefit of two eyes that work together for added visual efficiency as well as cosmetically straight eyes.

5. Compensation and Medical Care
   If you are injured in this study it is possible that you will not receive compensation or medical care from Pacific University, the investigators, or any organization associated with the study. All reasonable care will be used to prevent injury, however.

6. Alternatives Advantageous to Subjects
   An alternative approach to visual training is strabismus surgery, but any surgical procedure has serious risks associated with it.

7. Offer to Answer any Inquiries and Freedom to Withdraw
   The investigator will be happy to answer any questions that you may have at any time during the course of this study. You are free to withdraw your consent and to discontinue participation in this project or activity at any time without prejudice to you.

I have read and understand the above. _____ _____
Signed Date

If not 18 years of age or over, parent or guardian should sign below:

_____ _____ _____
Signature of parent or guardian Date Address
Phone: _____

Name and address of a person not living with you who will always know your address:

_____

CONTRACT

I agree to participate in the project titled "Evaluation of Biofeedback-Enhanced Visual Training for Exotropes," headed by Tricia Larsen and Marlene Inverso at the Pacific University College of Optometry, Forest Grove, Oregon.

As a participant in this project, I agree to attend biofeedback training sessions at Pacific University College of Optometry five days a week for thirty minutes a day, at a cost of $20.00 a week.

I understand that I will be refunded one half of the total fee if I attend enough sessions to meet the criteria of being able to hold my eyes straight in a dark, empty, and vertical line field upon command. I will also be refunded one half of the total fee even if I do not meet the criteria as long as I attend sessions until the principal investigators determine that I have exhausted the possibilities of this type of treatment for exotropia.

I have read and understand the above:

_____ _____

Signed Date

If the above undersigned is not 18 years of age or over, the parent or guardian should sign below:

_____ _____

Signature of Parent or Guardian Date

_____ _____

Address Phone

Name and address of a person not living with you who will always know your address:

_____

_____

RECORDING FORM FOR EXOTROPIC DEVIATION: BASELINE AND PRE AND POST BIOFEEDBACK TRAINING SESSIONS

BASELINE MEASUREMENTS

Date:	Subjective	Objective	Date:	Subjective	Objective
Distance					
Near					

PRE-BIOFEEDBACK SESSION MEASUREMENTS			POST-BIOFEEDBACK SESSION MEASUREMENTS	
Date:	Subjective	Objective	Subjective	Objective
Distance				
Near				
Date:				
Distance				
Near				
Date:				
Distance				
Near				
Date:				
Distance				
Near				
Date:				
Distance				
Near				
Date:				
Distance				
Near				
Date:				
Distance				
Near				
Date:				
Distance				
Near				

BIBLIOGRAPHY

1. Hirons RA and Yolton RL, "Biofeedback and Behavior Modification Techniques in Visual Training," JOURNAL OF THE AMERICAN OPTOMETRIC ASSOCIATION, 1978, 49 (8), 875-882.

2. Flom MC, Kirschen DG & Bedell HE, "Control of Unsteady Eccentric Fixation in Amblyopic Eyes by Auditory Feedback of Eye Position," INVEST. OPTH. VIS. SCI., Nov., 1980, pp. 1371-1381.

3. Schor C & Hallmark W, "Slow Control of Eye Position in Strabismic Amblyopia," INVESTI. OPHTHALMOL. VIS. SCI., June, 1978, pp. 577-581.

4. Abadi RV, Carden D & Simpson J, "A New Treatment for Congenital Nystagmus," BRITISH JOURNAL OF OPHTHAL., 1980, Vol. 64, pp. 2-6.

5. Cornsweet TN & Crane HD, "Research Note: Training the Visual Accommodiation System," VISION RESEARCH, Vol. 13, pp. 713-715, 1973 (Great Britain)

6. Trachtman JN, "Biofeedback of Accommodation to Reduce Functional Myopia: A Case Report," AMERICAN JOURNAL OF OPT. & PHYSIOL. OPTICS, Vol. 55, No. 6, pp. 400-406, June, 1978.

7. Granger L & Letourneau J, "Behavior Modification Techniques in Vision Training, " OPTOMETRIC WEEKLY, April 21, 1977, pp. 37-41.

8. Letourneau JE, "Application of biofeedback and Behavior Modification Techniques in Visual Training," JOURNAL OF OPT. & PHYSIOL. OPTICS, Vol. 53, No. 4, April, 1976, pp. 187-191.

9. Letourneau JE & Ludlam WM, "Biofeedback Reinforcement in the Training of Limitation of Gaze: A Case Report," JOURNAL OF OPT. & PHYSIO. OPTICS, Vol. 53, No. 10, Oct., 1976, pp. 672-675.

10. Cooper J and Feldman J, "Panoramic Viewing ...in the Intermittent Exotrope of the Diverging Excess Type," AMERICAN JOURNAL OF OPT. AND PHYS. OPTICS, Vol. 56, No. 7, pp. 422-429, July, 1979.

11. Palmer RD and Siegal M, "Electromyographic Feedback in Strabismus," Abstract in BIOFEEDBACK AND SELF-REGULATION, 1977, Vol. 2, No. 3, p. 316.

12. Van Brocklin MD, Vasche TR, Hirons RA, Yolton RL, "Biofeedback Enhanced Strabismum Therapy," accepted for PUBLICATION IN THE JOURNAL OF THE AMERICAN OPTOMETRIC ASSOCIATION, Dec., 1980.

13. Flom MC, "The Prognosis in Strabismum," AMERICAN JOURNAL OF OPT. AND ARCHIVES OF AMERICAN ACAD. OF OPT., Oct., 1958, pp. 509-514.

14. Ludlam WM, "Orthopitc Treatment of Strabismus," AMERICAN JOURNAL OF OPTOM. AND ARCHIVES OF AMERICAN ACAD. OF OPTOM., July , 1961, pp. 1-18.

Bibliography

15. Flax N and Duckman RH, "Orthoptic Treatment of Strabismus," JOURNAL OF THE AMERICAN OPTOMETRIC ASSOCIATION, Vol. 49, No. 12, Dec., 1978, pp. 1353-1361.

16. Skavenski AA & Steinman RM "Control of eye position in the dark," VISION RESEARCH 1970, 10, 193-203.

17. Skavenski AA "Inflow as a source of extraretinal eye position information," VISION RESEARCH 1972, 12, 221-229.

18. Monahan JS "Extraretinal feedback and visual localization," PERCEPTION AND PSYCHOPHYSICS, 1972, Vol. 12 (4)pp349-353.

19. Vaegan "Convergence and Divergence Show Large and Sustained Improvement after Short Isometric Exercise," AM J OPT & PHYSIOL OPTICS Vol. 56, No. 1, pp. 23-33 (1/79)

20. Haynes, HM Personal Communication, Feb. 1981.

21. Birnbaum, MM "The role of the trainer in Visual Training," JOURNAL OF THE AMER OPT ASSOC Vol. 48, No. 8., Aug. 1977, pp. 1035-39.

22. Mann, D "The role of Orthoptic Treatment," BRITISH ORTHOP. J. Vol. 4, 1947, pp. 30-34.

23. Balliet R & Nakayama K "Training of Voluntary torsion," INVESTIGATIVE OPHTHAL AND VIS SCI April 1978, Vol. 17, No. 4, pp. 303-314.

24. Smith WM "Control of Eye fixation by Auditory Feedback," PSYCHON SCI 1964, Vol. 1, pp. 233-234.